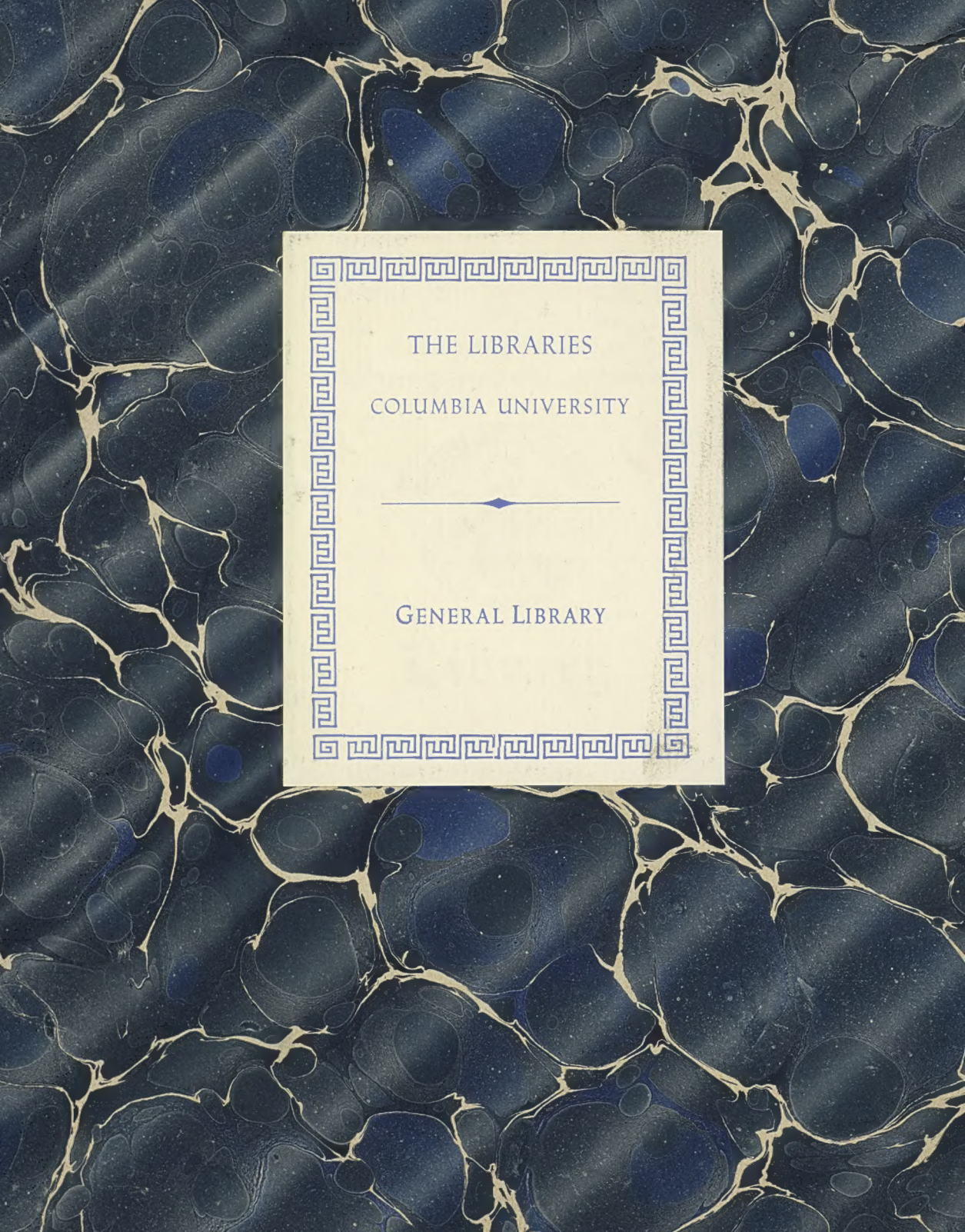
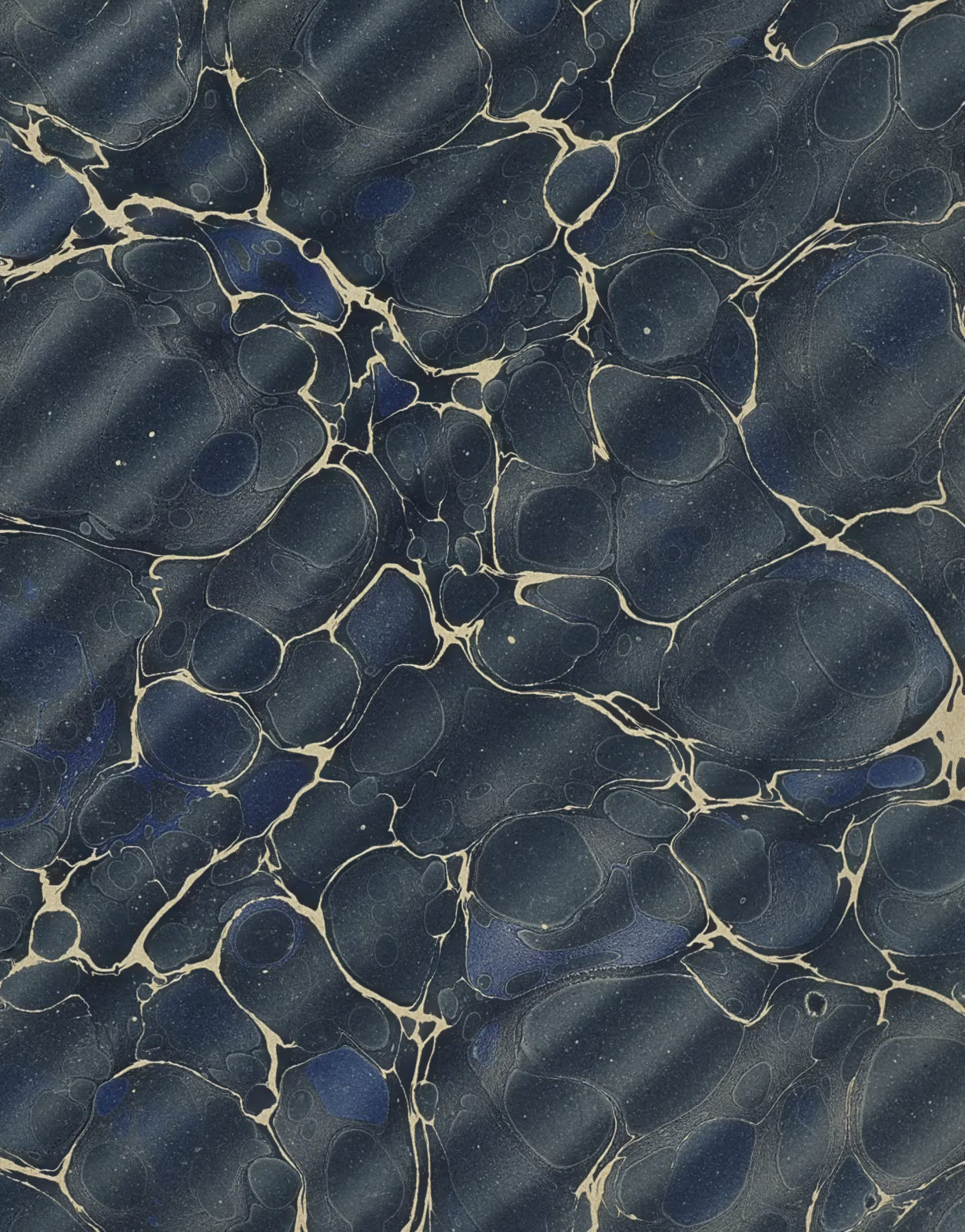

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OF THE

CORPS OF ENGINEERS.

VOLUME II.

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THE THEORY

OF

TERRESTRIAL MAGNETICS.

READ BEFORE THE ESSAYONS CLUB OF THE CORPS OF ENGINEERS,

MARCH 11, 1872;

BY

CAPTAIN CHARLES W. RAYMOND,
CORPS OF ENGINEERS.

NO. XX. PRINTED PAPERS.

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ERRATA.

Page 8, 7th line from the bottom. For the words *found from Eq.* (3) substitute the expression $m\,\phi\cos\theta\,\frac{H}{F}$

Page 9, 15th line. For *force* read *form.*

Page 11, 6th line of note. For *ereurs* read *erreurs.*

Page 14, 13th and 14th lines from the bottom. For *magnitism* read *magnetism.*

Page 16, 10th line from the bottom. For *at the time* read *of the time.* 11th line from the bottom. For *with* read *by.*

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THE THEORY OF TERRESTRIAL MAGNETICS.

A paper read before the "ESSAYONS CLUB" of the Corps of Engineers on March 11, 1872, by Capt. Charles W. Raymond, Corps of Engineers.

It is the purpose of this paper to develop the formulas and explain the methods employed in determining the elements of terrestrial magnetism from observations made with modern field magnetical instruments. In a subsequent paper, which I hope soon to lay before you, I shall describe these instruments and give detailed instructions for their adjustment and manipulation, with examples of the record and computations.

The duty of making field magnetical observations is one which any young officer of our corps may be called upon to perform; and unless he has had the benefit of previous instruction by some practical observer, I know of no publication which will give him the information which he will require concerning the use of modern instruments. This want is my excuse for attempting the preparation of these papers.

Were it within the scope of the present discussion, it would be extremely interesting to trace the progress of research in terrestrial magnetism during recent years, particularly in the United States. The admirable and extended system of observations instituted and carried out by the Coast Survey, and the thorough discussions of data by Professors Bache, Hilgard and Schott, which will be found in the publications of the Smithsonian Institution and in the reports of the Survey, would demand especial mention. The purpose of this discussion is however entirely practical, and its necessary limits will not permit digressions however tempting.

In order properly to ascertain the magnetic character of any locality at any time, two things must be determined;—first, the direction, and secondly, the intensity of the earth's magnetic force. The magnetic direction depends upon two elements;—first, the magnetic declination or variation, and secondly, the magnetic inclination or dip. The first is the angle included between the projection of the magnetic direction upon the plane

138012

of the horizon and the intersection of that plane with the plane of the true meridian. The second is the angle included between the magnetic direction and its horizontal projection. These two angles, together with the total intensity of the earth's magnetism, are called the magnetic elements. It is the object of magnetic observations to determine these elements for any time and place; and it will be the object of the present investigation to develop formulas by means of which these elements may be determined when suitable observations have been made.

As a basis for mathematical discussion, the magnetical hypothesis of Coulomb will be adopted. The discoveries in magnetism of recent years, particularly the results of the researches of Faraday in diamagnetism, render it impossible to accept this hypothesis as a theory adequate to the explanation of magnetic action.* Nevertheless, its accordance with the facts is sufficiently close for the purposes of this investigation, and it has been employed as a basis by Gauss and elaborately carried out in the analyses of Poisson. In this paper I shall follow the method of Poisson, adapting the investigation, however,

* The following extract, bearing on this point, appears as a note to one of the lectures of Prof. Tyndall.

"It is well known that a voltaic current exerts an attractive force upon a second current, flowing in the same direction; and that when the directions are opposed to each other the force exerted is a repulsive one. By coiling wires into spirals, Ampère was enabled to make them produce all the phenomena of attraction and repulsion exhibited by magnets, and from this it was but a step to his celebrated theory of molecular currents. He supposed the molecules of a magnetic body to be surrounded by such currents, which, however, in the natural state of the body mutually neutralized each other, on account of their confused grouping. The act of magnetization he supposed to consist in setting these molecular currents parallel to each other; and, starting from this principle, he reduced all the phenomena of magnetism to the mutual action of electric currents.

"If we reflect upon the experiments recorded in the foregoing pages from first to last, we can hardly fail to be convinced that diamagnetic bodies operated on by magnetic forces possess a polarity "the same in kind as, but the reverse in direction of that acquired by magnetic bodies." But, if this be the case, how are we to conceive the *physical mechanism* of this polarity? According to Coulomb's and Poisson's theory, the act of magnetization consists in the decomposition of a neutral magnetic fluid; the north pole of a magnet, for example, possesses an attraction for the south fluid of a piece of soft iron submitted to its influence, draws the said fluid toward it, and with it the material particles with which the fluid is associated. To account for diamagnetic phenomena this theory seems to fail altogether; according to it, indeed, the oft-used phrase, "a north pole exciting a north pole, and a south pole a south pole," involves a contradiction. For if the north fluid be supposed to be *attracted* toward the influencing north pole, it is absurd to suppose that its presence there could produce *repulsion*. The theory of Ampère is equally at a loss to explain diamagnetic action; for if we suppose the particles of bismuth surrounded by molecular currents, then, according to all that is known of electro-dynamic laws, these currents would set themselves parallel to, and in the same direction as those of the magnet, and hence attraction, and not repulsion, would be the result. The fact, however, of this not being the case proves that these molecular currents are not the mechanism by which diamagnetic induction is effected. The consciousness of this, I doubt not, drove M. Weber to the assumption that the phenomena of diamagnetism are produced by molecular currents, not *directed* but actually *excited* in the bismuth by the magnet. Such induced currents would, according to known laws, have a direction *opposed* to those of the inducing magnet, and hence would produce the phenomena of repulsion. To carry out the assumption here made, M. Weber is obliged to suppose that the molecules of diamagnetic bodies are surrounded by channels, in which the induced molecular currents, once excited, continue to flow without resistance."—*Diamagnetism and Magne-crystallic Action* pp. 136, 137.

to the development of formulas suitable to modern methods, and extending the discussion to determinations by a deflecting magnet out of the meridian, a case not treated by Poisson, so far as I am aware.

The hypothesis of Coulomb consists essentially in the assumption of two magnetic fluids, the *austral* or positive, and the *boreal* or negative, co-existing in a state of equilibrium or combination in all bodies. Each of the two fluids is repulsive of itself and attractive of the other. In some substances, such as iron or steel, these two fluids may be separated by the inductive influence of the earth or of another magnet.

In the ordinary condition of a body capable of magnetization, each atom contains equal quantities of the two fluids, and the process of magnetization consists in the disturbance of the equilibrium between them by the removal of a small quantity of one kind of fluid and the substitution of an equal quantity of the other. After magnetization each atom still contains a quantity of each fluid, but one fluid is in excess of the other; and it is this *free fluid* or *free magnetism*, as it is termed, whose effects we are to consider, since the forces exerted by the remainder of the two fluids are equal and opposed, and consequently neutralize each other.

The term *magnet* will be employed in this paper to designate a bar of steel, symmetric and symmetrically magnetized about a right line joining two points, A and B, at its extremities, and passing through its centre of gravity G. This line will be termed the magnetic axis. The magnet will be supposed to be permanent, that is, the quantity of free fluid, varying from one point to another, remains constant for each infinitely small element of volume, being retained by what is called the *coercitive* force of the material.

By the process of magnetization, equal quantities of the two fluids contained in each element of volume are very slightly separated from each other, very nearly parallel to the magnetic axis, in such a way that all the displaced particles of the same fluid approach one extremity, A or B, of this axis, and recede from the other. The magnetic force of the earth at any place is, therefore, exerted with equal intensity upon equal quantities of the two fluids, in parallel but opposite directions. Hence, if a magnet be freely suspended at its centre of gravity, and submitted solely to the magnetic action of the earth, the motive forces upon all its points, referred to that centre, will be destroyed, two by two, and without displacement of that point, the magnetic axis will take the common direction of these forces.

It has been determined by observation that in each magnetic hemisphere the same extremity of the same magnet, freely suspended at its centre of gravity, is always elevated or depressed above or below the horizontal plane passing through this centre, the

extremity which is elevated in the northern hemisphere being depressed in the southern. The extremity which falls in the northern hemisphere and rises in the southern is called the *austral pole* of the magnet, and the extremity which rises in the northern, and falls in the southern hemisphere is called the *boreal pole*. We may then define *austral fluid* as that fluid whose particles in the act of magnetization approach the austral, or recede from the boreal pole of the magnet, and *boreal fluid* as that fluid whose particles approach the boreal, or recede from the austral pole during the same process. In this discussion A will represent the austral, and B, the boreal pole.

Let a and b represent the two parts AG, BG of the magnetic axis. Let u represent the distance of any point on the magnetic axis from the point G. This distance will be regarded as positive for all points situated between A and G, and as negative for all points situated between G and B. Conceive the magnet to be divided into infinitely thin transverse sections each having the thickness du. Let $f(u)\,du$ represent the quantity of free magnetism which is contained by the section at a distance u from G, and which will be regarded as positive or negative according as it is austral or boreal fluid which is in excess. The quantity $f(u)$ will be a function of u depending upon the distribution of the two fluids along the magnet, or upon the mode of magnetization. Since the magnetic particles, in this operation, experience displacements which are insensible in extent, it follows that this function will pass from positive to negative for values of u whose difference is equally insensible. The quantities of the two fluids will be equal in the entire magnet, and we shall have

$$\int_{-b}^{a} f(u)\,du = 0 \quad - - - - - - - - - \quad (1)$$

For the elementary magnetic moment with reference to the point G we shall have the expression $u\,f(u)\,du$, and for the statical moment of the free fluid in the whole magnet,

$$\int_{-b}^{a} u\,f(u)\,du.$$

This integral will not, however, be equal to zero. The particles of austral fluid, in the process of magnetization, being drawn towards A or repelled from B, and those of boreal fluid being drawn towards B or repelled from A, it follows that this integral, taken from B to A, will always be a positive quantity. Hence we may write

$$\int_{-b}^{a} u\,f(u)\,du = m.$$

Let $\phi\,f(u)\,du$ represent the motive force of $f(u)\,du$, due to the magnetic action of the earth and equivalent to a weight infinitely small. The coefficient ϕ repre-

sents an accelerating force which will be positive for both fluids, and constant in amount and direction throughout the entire length of the magnet. Hence we shall have for the total integral of $\varphi f(u)\, du$,

$$\varphi \int_{-b}^{a} f(u)\, du = 0$$

whence it follows that if the magnet be freely suspended by a vertical filament passing through its centre of gravity, the action of the earth not tending to displace that centre, the filament will always preserve its direction. The magnet having assumed its position of equilibrium, the force $\varphi f(u)\, du$ will act in the direction of the magnetic axis, but repelling towards A or B the free fluid $f(u)\, du$, according as it is austral or boreal; that is according as $f(u)$ is positive or negative.

Whatever may be the direction of the magnet when not freely suspended, the horizontal and vertical components of the force φ will always remain parallel to the plane of the magnetic meridian, and their values will be respectively $\varphi \cos \theta$, $\varphi \sin \theta$, θ representing the angle of inclination. If it be constrained to move only in a fixed vertical plane, the component $\varphi \cos \theta$ may be itself decomposed into two components, one perpendicular to the plane and neutralized by its resistance; the other in the plane; and designating by α the magnetic azimuth, this last component will have for its value $\varphi \cos \theta \cos \alpha$.

Without displacing the magnetic axis from the magnetic meridian, we may cause the magnet, when freely suspended at its centre of gravity, always to assume a horizontal position, by fixing at some point of the axis a weight w, composed of some non-magnetizable substance in order not to change the value of m. Representing by h, the distance from the centre to the point at which the weight is fixed, the moment of the weight w with respect to the point G will be wh. The moment of the vertical force $\varphi \sin \theta f(u)\, du$ (applied at the distance u from G) with reference to the same point is $u \varphi \sin \theta\ f(u)\, du$, and consequently the sum of the moments of the vertical components of the earth's action on the entire magnet will be

$$\varphi \sin \theta \int_{-b}^{a} u\ f(u)\, du = m\, \varphi \sin \theta$$

hence

$$wh = m\, \varphi \sin \theta \quad - - - - - - - \quad (2)$$

which is the equation of equilibrium of the horizontal magnet. As a consequence of this equation, the weight w and the vertical components of the earth's magnetism will balance each other in every azimuth.

Let δ represent the magnetic declination at any place and time. In practice this angle is determined by suspending a magnet horizontally by one or more filaments of silk, and measuring its angular deviation from the true meridian. The instrument employed is provided with apparatus by means of which the line of torsion at the moment of adjustment is turned into the plane of the magnetic meridian. For any subsequent time at which the variation from this zero of declination is observed it is evidently necessary to correct the observed angle for the resistance to torsion due to the suspension.

Let δ' represent the declination at the time of adjustment; α, the observed change in the value of δ at any subsequent instant, and β, the difference between α and its value independent of torsion. Then

$$\delta = \delta' \pm (\alpha + \beta)$$

Since the moment of torsion is proportional to the angle of torsion it may be represented by $\gamma\alpha$. For this position of the magnet, the moment with reference to the point G of the horizontal force $\varphi \cos\theta f(u)\, du$, applied parallel to the meridian at the point whose distance from G is u, will be equal to the product of that force and the perpendicular $u \sin\beta$ let fall from the point G upon its direction; hence the sum of the moments of all the horizontal components of the magnetic action of the earth will be

$$\varphi \cos\theta \sin\beta \int_{-b}^{a} u\, f(u)\, du = m\, \varphi \cos\theta \sin\beta$$

Consequently, in order that these forces may equilibrate the torsion, we must have

$$m\, \varphi \cos\theta \sin\beta = \gamma\alpha$$

and, since β is very small, we may write

$$\beta = \frac{\gamma\alpha}{m\, \varphi \cos\theta}$$

Representing $\frac{\gamma}{m\, \varphi \cos\theta}$ by the symbol $\frac{H}{F}$, which is the usual notation, we obtain

$$\delta = \delta' \pm \alpha \left(1 + \frac{H}{F}\right) \quad - - - - - - - - - - - \quad (3)$$

In order to obtain the value of the constant ratio in the second member of this equation, let the suspension thread be twisted through an angle ω, and let α' represent the corresponding change in the value of α. For this case we shall have

$$\alpha' = \frac{H}{F}(\omega - \alpha')$$

hence

$$\frac{H}{F} = \frac{\alpha'}{\omega - \alpha'} \quad - - - - - - - - - - - \quad (4)$$

Equations (3) and (4) determine the magnetic declination when α has been found by observation and α', by experiment.

The magnet being horizontal and the zero of torsion coincident with the magnetic meridian, let it be made to oscillate around a vertical axis. Its oscillations will be similar to those of a pendulum, since all its points will be submitted to a force constant in magnitude and direction like the force of gravity.

Let ψ represent the angle comprised between the magnetic axis and the magnetic meridian at the end of any time t. The sum of the moments with respects to the point G, of the horizontal components of the earth's magnetic force will then be represented by $m\,\varphi\cos\theta\sin\psi$. The moment of torsion of the suspending filament will be $\gamma\psi$. Let K represent the moment of inertia of the suspended mass; then, from a well known formula, we have

$$K\frac{d^2\psi}{dt^2} = -m\,\varphi\cos\theta\sin\psi - \gamma\psi \quad - - - - - - - - \quad (5)$$

The angle ψ corresponding to any oscillation must be very small, so that we may consider t as independent of the resistance of the air, since, as in the case of an ordinary pendulum, the only effect of this resistance is to gradually diminish the arcs of vibration without affecting their duration.

Multiplying both members of Eq. (5) by $2\,d\psi$, and integrating, we obtain

$$K\left(\frac{d\psi}{dt}\right)^2 = 2\,m\,\varphi\cos\theta\cos\psi - \gamma\,\psi^2 + C$$

Denoting the initial value of ψ by ψ', we have, since the angular velocity is, at the corresponding instant, equal to zero,

$$2\,m\,\varphi\cos\theta\cos\psi' - \gamma\,\psi'^2 + C = 0$$

whence, eliminating C,

$$K\left(\frac{d\psi}{dt}\right)^2 = 2\,m\,\varphi\cos\theta\,(\cos\psi - \cos\psi') + \gamma\,(\psi'^2 - \psi^2) \quad - - - - - \quad (6)$$

Developing $\cos\psi$ and $\cos\psi'$, we have

$$\cos\psi = 1 - \frac{\psi^2}{1.2} + \frac{\psi^4}{1.2.3.4} - \&c.$$

$$\cos\psi' = 1 - \frac{\psi'^2}{1.2} + \frac{\psi'^4}{1.2.3.4} - \&c.$$

and neglecting terms involving the fourth and higher powers, since the arcs of oscillation are very small, we obtain

$$\cos\psi - \cos\psi' = \frac{\psi'^2 - \psi^2}{2}$$

Substituting in Eq. (6), and solving with reference to dt, we have

$$dt = -\sqrt{\frac{K}{m\,\varphi\,\cos\theta+\gamma}}\,\frac{d\phi}{\sqrt{\phi'^2-\phi^2}}$$

the negative sign being taken because ϕ is a decreasing function of the time.

Integrating, we obtain

$$t = -\sqrt{\frac{K}{m\,\varphi\,\cos\theta+\gamma}}\,\cos^{-1}\frac{\phi}{\phi'}$$

the constant of integration being equal to zero, since for $\phi=\phi'$ we have $t=0$.

At the instant when the axis of the magnet coincides with the line of equilibrium we shall have $\phi=0$, and representing by t_1 the whole interval from $\phi=\phi'$ to $\phi=0$, we shall have

$$t_1 = -\sqrt{\frac{K}{m\,\varphi\,\cos\theta+\gamma}}\,\frac{\pi}{2}$$

But since the earth's magnetic force is by hypothesis constant in magnitude and direction, the impetus acquired by the magnet during its accelerated motion between $t=0$ $t=t_1$ will carry it past the position of equilibrium in such a way as to determine a precisely similar phase in reverse order on the opposite side of this position. Hence we shall have for the interval corresponding to one complete oscillation from $\phi=\phi'$ to $\phi=-\phi'$,

$$t = \pi\sqrt{\frac{K}{m\,\varphi\,\cos\theta+\gamma}} \quad \text{- - - - - - - - - - (7)}$$

whence

$$m\,\varphi\,\cos\theta = \frac{\pi^2 K}{t^2} - \gamma$$

Substituting for γ its value found from Eq. (3), and reducing, we obtain

$$m\,\varphi\,\cos\theta = \frac{\pi^2 K}{t^2}\left(\frac{1}{1+\frac{H}{F}}\right)$$

Placing $T^2 = t^2\left(1+\frac{H}{F}\right)$, and substituting, we obtain

$$m\,\varphi\,\cos\theta = \frac{\pi^2 K}{T^2} \quad \text{- - - - - - - - - - (8)}$$

an equation which completely determines the product of the magnetic moment of the suspended magnet and the horizontal intensity of the earth's magnetism when K and T have been determined by experiment.

As before indicated, K represents the moment of inertia of the suspended mass, which consists of the magnet and the stirrup in which it rests. It cannot be conveniently determined directly, and is therefore obtained by experiment. The experiment consists in loading the magnet symmetrically with reference to the axis of suspension, the weight and dimensions of the load having been previously determined with the greatest possible accuracy, and timing the oscillations of the suspended mass.

Let K' = moment of inertia of the suspended magnet, stirrup and load.

K'' = moment of inertia of the load.

T' = corrected time of a single oscillation of the magnet thus loaded.

Then from Eq. (8), assuming that $m \varphi \cos \theta$ remains constant for both sets of oscillations, we have

$$\frac{K}{T^2} = \frac{K'}{T'^2}$$

hence, since $K' = K + K''$,

$$\mathrm{K} = \mathrm{K}'' \frac{T^2}{T'^2 - T^2} \quad \text{- - - - - - - - - - - - (9)}$$

A small correction must be applied for changes in the dimensions or force of the suspended mass due to changes of temperature. It consists in multiplying K by $1 + 2\varepsilon(t' - t)$, in which t' denotes the actual temperature of the magnet, t the temperature corresponding to the time of original observations, and ε the coefficient of dilation of steel for one degree Fahrenheit, which is equal to 0.0000068.

The load usually employed in these experiments is a ring of bell-metal, which is balanced upon the magnet. To determine K″ for this case, let

r = outer radius of ring in decimals of a foot.

r' = inner radius of ring in decimals of a foot.

w = weight of ring in grains.

Then $$\mathrm{K}'' = \frac{1}{2}\left(r^2 + r'^2\right) w \quad \text{- - - - - - - - - - - (10)}$$

If the load consists of two cylindrical weights of equal dimensions suspended at opposite ends of the magnet, then

$$\mathrm{K}'' = \left(\tfrac{1}{2} l^2 + r^2\right) p \quad \text{- - - - - - - - - - - (11)}$$

in which l represents the interval of the points of suspension, r the radius of the cylinders, and $2p$ their mass, expressed respectively in feet and grains.

We have thus obtained formulas for the determination of the product of the magnetic moment of the suspended magnet and the earth's horizontal magnetic intensity; but, in order to separate these quantities, we must find a method of determining some other function of them, which by combination with the first value will give the required results. The general method of determining such a function is to suspend a second magnet, and submit it simultaneously to the action of terrestrial magnetism and that of the magnet before employed. The moment of each of these forces, taken with reference to any axis, will depend upon the distribution of free magnetism in the suspended magnet; and, in addition to this, the moment of the second force will depend upon the distribution of free magnetism in the other magnet, the distance between the centres of the magnets, the position of the right line joining these centres with reference to the two magnetic axes, and finally, upon the law of magnetic action, which is, that the mutual action of two elements of magnetic fluid upon each other varies directly as the quantity of the two fluids and inversely as the square of the distance between them. This law has been verified by a vast number of experiments.

There are two methods of conducting this experiment. We may cause the suspended magnet to oscillate and observe the effect of the two forces combined upon the duration of its oscillations; or we may observe its position in a state of equilibrium under the influence of the same action.

In the first case, the magnetic axis of the deflector is fixed in the plane of the magnetic meridian, at a convenient distance, and in such a way that its prolongation passes through the centre of the oscillating magnet. The oscillations will be accelerated or retarded according as like or unlike poles are presented to each other; and, from a comparison of the times of vibration in these two positions of the deflector, or from a comparison of either of these times with the time of oscillation when the deflector is removed, the relation between the terrestrial horizontal intensity and the action of the deflector may be ascertained. This is the method of Poisson.

In the second case, the deflector is fixed in some position out of the magnetic meridian, the prolongation of its axis passing through the centre of the suspended magnet, and the deflection of the latter from the magnetic meridian is observed. From the amount of this deflection the relation between the terrestrial horizontal intensity and the action of the deflector is determined. This method is due to Gauss.

For theoretical and practical reasons, which I need not here consider, the last method is the one now almost universally adopted.* This discussion will therefore be con-

* "Au reste, le premier de ces deux procédés est au fond le même que l'illustre Poisson a proposé il y a déjà quelques années. Mais les expériences tentées d'après sa méthode par quelques physiciens (autant du

fined to the consideration of that method : or rather, to the consideration of a particular case of it, which was, I believe, first employed by Dr. Lamont of Munich. The advantages of this particular method will appear as we proceed.

For simplicity I shall suppose the magnetic fluids to reside wholly in the magnetic axes; an assumption which will not prevent the attainment of all desirable accuracy in our final results.

Let a magnet M' be suspended horizontally in the magnetic meridian, and let the magnet M, which has before been suspended and oscillated to determine the value of $m\varphi\cos\theta$, be fixed horizontally in a line perpendicular to the magnetic meridian and passing through the centre of suspension. Let r represent the distance between the centres of the magnets. The mutual action of the two magnets upon each other will deflect the magnet M' from its position in the magnetic meridian.

Suppose the deflecting magnet to be moved in its own horizontal plane, in the direction of the deflection, in such a way that the prolongation of its axis continues to pass through the centre of the suspended magnet, the distance r remaining unchanged, until it attains a position in which the axes of the magnets are at right angles to each other. In this position let α represent the angle included between the axis of M' and the magnetic meridian.

The distance apart of the elementary sections du (of M) and du' (of M') will then be represented by

$$\sqrt{(r-u)^2+u'^2}$$

and, since the mutual action of the two elementary quantities of free magnetic fluid $f(u)\,du, f(u')\,du'$, obeys the law of gravitative action, varying directly as the quantities

moins qu'elles sont venues à ma connaissance) ou bein n'ont eu aucun succés, ou bien n'ont fourni seulement qu'une grossière approximation.

"La difficulté de la chose tient principalement à cette circonstance que d'après les actions d'une aiguille observées dans des distances peu considérables, il faut conclure une certaine limite de force qui se rapporte pour ainsi dire à une distance indéfiniment grande, et que les éliminations nécessaires pour atteindre ce but sont d'autant plus sujettes à être influencées (et même tout-à-fait rendues illusoires) par les légères erreurs des observations qu'il y a à éliminer un plus grand nombre d'inconnues dépendant de l'état individuel des aiguilles. On ne peut réduire à un trés petit nombre les inconnues en question qu'autant seulement que l'on observe les actions réciproques à des distances assez grandes comparativement à la longueur des aiguilles, et alors ces actions deviennent extrêmement petites. Mais pour mesurer ces actions si petites, les moyens pratiques mis en usage jusqu'ici sont tout-à-fait insuffisans." *Gauss.—Annales de Chimie et de Physique.* t. lvii. 1834.

of the two fluids and inversely as the square of the distance between them, we shall have for the expression of that mutual action

$$\frac{f(u)f(u')\,du\,du'}{(r-u)^2+u'^2}$$

in which the unit of action is the mutual action of a unit of quantity of each free fluid at a unit of distance. The lever-arm of this force with reference to the line of suspension of M' will be

$$\frac{(r-u)\,u'}{\sqrt{(r-u)^2+u'^2}}$$

hence we shall have for the total statical moment of the magnetic forces emanating from all the points of the fixed magnet M, and acting upon all the points of the movable magnet M', the expression

$$\int\int \frac{(r-u)\,u'f(u)f(u')\,du\,du'}{\sqrt{((r-u)^2+u'^2)^3}}$$

in which the double integral extends to the entire length of each magnet.

The direct action of the earth upon the magnet M' is represented by the moment

$$\varphi\cos\theta\sin\alpha\int u'f(u')\,du'$$

and since, in practice, the line of torsion lies in the vertical plane containing the axis of M', the condition of equilibrium between the forces gives us the equation

$$\int\int\frac{(r-u)u'f(u)f(u')\,du\,du'}{\sqrt{((r-u)^2+u'^2)^3}}=\varphi\cos\theta\sin\alpha\int u'f(u')\,du'$$

Developing the factor $\dfrac{(r-u)u'}{\sqrt{((r-u)^2+u'^2)^3}}$ in terms of the ascending negative powers of r, we obtain

$$\int\int\frac{(r-u)u'f(u)f(u')\,du\,du'}{\sqrt{((r-u)^2+u'^2)^3}}=$$

$$\int\int\frac{1}{r^2}\left[u'+\frac{2}{r}uu'+\frac{3}{2r^2}\left(2u^2u'-u'^3\right)+\frac{2}{r^3}\left(2u^3u'-3uu'^3\right)+\cdots\right]f(u)f(u')\,du\,du'.$$

But we have by Eq. (1), $\int f(u)\,du=0, \int f(u')\,du'=0$; and as each magnet is assumed to be magnetized symmetrically on opposite sides of its centre of gravity, the integrals $\int u^2 f(u)\,du, \int u'^2 f(u')\,du'$, having even numbers for exponents of the distances u and u', must vanish. Representing $\int u f(u)\,du$ by m, $\int u' f(u')\,du'$ by m', $\int u^3 f(u)\,du$ by m_3 and $\int u'^3 f(u')\,du'$ by m'^3 in order to simplify subsequent expressions, we have, after reduction, and substitution in the equation of equilibrium,

$$\frac{2\,m\,m'}{r^3}+\frac{4\,m'\,m_3-6\,m\,m'_3}{r^5}=m'\,\varphi\,\cos\theta\,\sin\alpha$$

from which we obtain

$$\frac{m}{\varphi\,\cos\theta}=\frac{1}{2}\,r^3\,\sin\alpha\left[1+\frac{1}{r^2}\left(\frac{2\,m_3}{m}-3\,\frac{m'_3}{m'}\right)\right]^{-1}$$

Developing the binomial factor of the second number in terms of its second term, and neglecting all except the first two terms of the resulting series, since r is very great compared with u and u', we obtain

$$\frac{m}{\varphi\,\cos\theta}=\frac{1}{2}r^3\,\sin\alpha\left(1-\frac{P}{r^2}\right), \quad - - - - - - - - - - \quad (12)$$

in which equation

$$P=2\frac{m^3}{m}-3\frac{m'^3}{m'}$$

It is evident that P is constant for any given pair of magnets. In order to discuss its value I shall assume, in accordance with the determinations of Lambert, that the quantity of free fluid at any point of the magnet is in direct proportion to the first power of its distance from the magnetic centre. Substituting Au and $A'u'$ for $f(u)$ and $f(u')$ respectively in the terms of which the value of P is composed, (A and A' representing constants), and integrating for the entire length of each magnet, we obtain

$$P=\frac{6l^2}{20}-\frac{9l'^2}{20}$$

in which l and l' represent the lengths of the magnets M and M' respectively.

From this equation we readily draw the following conclusions:

1. In order to have the value of P as small as possible the longer magnet should be the deflector.

2. The value of P decreases as the relation between the lengths of the magnets approaches the proportion of 1.000 to 1.224, at which it disappears.

3. The value of P is greatest when the magnets are equal in length, unless their lengths are to each other in the proportion of 1.000 to 1.732, or there is a greater difference between them; a case which I presume never occurs in practice.

The practical method of determining the value of P, which I will now explain, is entirely independent of any assumption concerning the form of the functions $f(u)$, $f(u')$.

Let deflections be observed at two distances, r and r', of which r' is the greater. Then we have for these cases the equations

$$\frac{m}{\varphi \cos\theta} = \frac{1}{2} r^3 \sin\alpha \left(1+\frac{P}{r^2}\right)^{-1}$$

$$\frac{m}{\varphi \cos\theta} = \frac{1}{2} r'^3 \sin\alpha' \left(1+\frac{P}{r'^2}\right)^{-1}$$

Combining these equations so as to eliminate $\frac{m}{\varphi \cos\theta}$, and solving with reference to P, we obtain

$$P = -\frac{r^2 r'^5 \sin\alpha' - r'^2 r^5 \sin\alpha}{r'^5 \sin\alpha' - r^5 \sin\alpha}.$$

Equation (12) determines the ratio of the horizontal intensity of the earth's magnitism to the magnetic moment of the deflecting magnet.

It is evident that the accuracy of the determination increases as we increase the distance between the magnets, since we have neglected in the discussion terms containing the higher negative powers of r. Moreover, there appears to me to be another reason why r should be large in comparison with the lengths of the magnets. Whatever degree of magnetic permanence the magnets employed may possess, it must be remembered that there is no steel so hard as not to be capable, in some degree, of magnetic induction; hence the repulsive action of one magnet on the other must always be less than its attractive action, since the repulsion is opposed, while the attraction is assisted by the inductive action. It would seem that, even with the best material, this cause might seriously affect the accuracy of the result, were the magnets separated by a small distance. There is, however, a practical limit to the distance r, since, by its undue increase, we may diminish the angle α below the limits of accurate measurement.

Combining Eqs. (8) and (12), and finding successively the values of m and $\varphi \cos \theta$, we obtain

$$m = \frac{\pi r}{T} \sqrt{\frac{Kr \sin \alpha \left(1 - \frac{P}{r^2}\right)}{2}} \quad - - - - - - - - - (13)$$

$$\varphi \cos \theta = \frac{\pi}{Tr} \sqrt{\frac{2K}{r \sin \alpha \left(1 - \frac{P}{r^2}\right)}} \quad - - - - - - - - - (14)$$

These equations involve the assumption that the values $\varphi \cos \theta$ and m remain constant throughout both series of experiments. Nevertheless, experience abundantly proves that the magnetic condition of the earth is, at every point, constantly undergoing change; nor is the assumption of permanence in the magnets supported by the facts. We are, however, generally compelled to assume the constancy of the value of $\varphi \cos \theta$, since it is impracticable to measure its variations at short intervals with the apparatus usually employed on magnetic surveys; and undoubtedly we may make the assumption with little danger of material error, when the experiments have been made as near each other as possible in point of time.

The value of m is subject to a twofold change. In the introduction to this discussion I assumed the magnets to be permanent; that is, that the quantity of free fluid remains constant for each element of volume, being retained by the coercitive force of the material. In point of fact, however, no material is endowed with coercitive force to such an extent as to retain completely a constant magnetic condition; so that even the most perfect magnets are continually undergoing a gradual diminution of power. The change in m due to this cause is quite inappreciable for short intervals, and may be safely neglected.

The value of m is, however, subject to a change of a more important character. Experiment proves that the magnetic condition of a body varies with its temperature, an increase of heat producing a diminution of magnetic intensity. The original magnetic condition is restored with the original temperature, unless the body has been raised to a great heat. This mutual dependence of the temperature and the magnetic force must be determined by appropriate experiments; and, if the experiments of vibration and deflection have been made at different temperatures, they must be reduced to the same temperature by the application of suitable corrections.

Having agreed, then, to regard $\varphi \cos \theta$ as a constant in Eqs. (8) and (12), two methods of effecting the required reduction present themselves. We may either reduce

the value of m in Eq. (8) to what it would be at the temperature corresponding to the experiments of deflection, or we may reduce its value in Eq. (12) to what it would be at the temperature corresponding to the experiments of vibration. The first method is, perhaps, the most convenient, and I shall therefore confine myself to its consideration.

Let m' represent the magnetic moment of the magnet at the time of vibration, and m the same quantity at the time of deflection; t' and t, the corresponding temperatures. We may assume, without fear of material error, that the change in the value of the magnetic moment is proportional to the change in temperature. We have, therefore, the equation

$$m = m'(1 - q(t - t'))$$

in which q represents the change in the magnetic moment due to a change of one degree in temperature.

If we represent by T' the time of oscillation corresponding to the moment m', we obtain

$$m = \frac{\pi^2 K}{\varphi \cos\theta} \cdot \frac{1 - q(t-t')}{T'^2}$$

Since q is very small we may neglect terms containing its higher powers; hence we may write

$$m = \frac{\pi^2 K}{\varphi \cos\theta} \cdot \frac{1}{T'^2(1-q(t'-t))}$$

The expression $(1-q(t'-t))$ is, then, a coefficient with which if we multiply the square at the time of vibration at the temperature t', we obtain the required square of the time at the temperature t.

We must now determine the value of q, which is, by assumption, constant for a given magnet. For this purpose let us suppose that two series of experiments of vibration have been made at widely differing temperatures $t_{,}$ and $t_{,,}$. Corresponding to these temperatures we shall have the equations

$$T_{,}^2 = \frac{\pi^2 K}{m_{,} \varphi \cos\theta} \qquad T_{,,}^2 = \frac{\pi^2 K}{m_{,,} \varphi \cos\theta}$$

Let us now represent by $m_\circ$ the moment corresponding to the zero of temperature. We shall then have

$$m_{,} = m_\circ(1 - qt_{,}) \qquad m_{,,} = m_\circ(1 - qt_{,,})$$

Substituting these values in the two proceeding equations, we obtain

$$T_{,}^{2}=\frac{\pi^2 K}{m_{\circ}\varphi \cos\theta\,(1-qt_{,})} \qquad T_{,,}^{2}=\frac{\pi^2 K}{m_{\circ}\varphi \cos\theta\,(1-qt_{,,})}$$

whence we have

$$T_{,}=\sqrt{\frac{\pi^2 K}{m_{\circ}\varphi \cos\theta\,(1-qt_{,})}}=\sqrt{\frac{\pi^2 K}{m_{\circ}\varphi \cos\theta}}\;(1+\frac{1}{2}qt_{,}+\cdots)$$

$$T_{,,}=\sqrt{\frac{\pi^2 K}{m_{\circ}\varphi \cos\theta\,(1-qt_{,,})}}=\sqrt{\frac{\pi^2 K}{m_{\circ}\varphi \cos\theta}}\;(1+\frac{1}{2}qt_{,,}+\cdots)$$

Combining these equations so as to eliminate the radical factor, and solving with refererence to q, we obtain

$$q=2\frac{T_{,}-T_{,,}}{T_{,,}t_{,}-T_{,}t_{,,}} \quad \cdots\cdots\cdots \quad (15)$$

which is the required value.

Let us now suppose T, in Eqs. (13) and (14), to represent the time of an oscillation corrected for the torsion of the suspension, and reduced to the temperature t, corresponding to the experiments of deflection. These equations will then respectively determine the values of the magnetic moment of the vibrating and deflecting magnet, and the horizontal component of the intensity of the earth's magnetism.

Representing the horizontal intensity $\varphi \cos\theta$ by X, we have for the total intensity

$$\varphi = X \sec\theta \quad \cdots\cdots\cdots \quad (16)$$

Corresponding to the numerical value of φ obtained from Eq. (16), there must be a unit force of the same nature depending upon the units before assumed. The fundamental units in the preceding discussion are the units of distance, mass and time, for which we have assumed one foot, one grain and one mean solar second. In addition to these we require a unit of velocity, a unit of force and a unit of free magnetism. The unit of velocity is the velocity which corresponds to the unit distance, passed over in uniform motion during the unit time; the unit of force is the accelerating force which, acting during the unit time upon the unit mass, will generate the unit velocity; and, finally, the unit of free magnetism is the quantity of free fluid which, acting upon an equal quantity through the unit distance, will develop a motive force equal to the unit force. If we desire we may of course take the accelerating force of gravity at the place of observation as the unit force, instead of the absolute unit above assumed.*

* See note at the end of the paper.

The term *needle* will be employed in this paper to designate a magnet so arranged as to move freely in a vertical plane only, about a horizontal axis passing through its centre of gravity.

The magnetic inclination θ, or as it is generally termed, the *dip*, is usually ascertained directly by observing the direction assumed by a magnetic needle suspended in the plane of the magnetic meridian. Before showing how the value of θ may be otherwise obtained, I will explain a method by which the dip and relative intensity of the earth's magnetism may be determined from a single set of observations with the dipping-needle. This method is more reliable in some latitudes than the usual method heretofore explained. It was devised and first employed by Prof. Lloyd in the magnetic survey of Ireland, and bears the name of *Lloyd's Statical Method.**

This method consists in observing the direction assumed by an ordinary dipping-needle under the combined influence of magnetism and gravity. Let two small weights be successively attached to the southern arm of the needle. Let ν and ν' represent the moments of the weights; ζ and ζ' the inclinations of the needle in the two cases; φ, the relative force, and σ a constant depending upon the distribution of magnetism in the needle. Then

$$\nu \cos \zeta = \varphi, \sigma \sin (\theta - \zeta) \qquad \nu' \cos \zeta' = \varphi, \sigma \sin (\theta - \zeta')$$

Hence if ν and ν' be known, and the angles ζ and ζ' be observed, the two unknown quantities θ and φ, will be completely determined.

The friction of the axle, however, which is the main source of error in the dipping-needle, will affect the quantities differently in different positions. Prof. Lloyd finds from theory that the limit of error in the determination of the *dip* arising from this cause will be least when the position of the needle coincides with the line of the dip, while that of the *force* is least when the needle is at right-angles to that line. Hence the best mode of applying the method consists in observing successively the position of the needle when unloaded, and its position when loaded with a weight sufficient to render it nearly perpendicular to the line of the dip.

As the inclination of the needle in the first position is nearly equal to the dip, and would be accurately so if the centre of gravity of the needle perfectly coincided with the axle, it is convenient to consider this first angle as the approximate value of the dip, and to seek the correction required in order to reduce it to its true value.

* Transactions of the British Association—1835.

If ε denote this correction, it can be readily shown from the formulas before given that

$$\theta=\zeta+\varepsilon \qquad \sin\varepsilon=\rho\frac{\cos\zeta}{\cos\zeta'}\sin(\zeta-\zeta') \quad (17)$$

in which ρ represents the ratio of the moment of the needle itself to that of the weight afterwards added.

The force is deduced from the second position of the needle when loaded, and is given by the formula

$$\varphi=\frac{\beta\cos\zeta'}{\sin(\theta-\zeta')} \quad (18)$$

in which β is a constant determined from the values of θ and ζ' at the place where the force is taken as unity.

Prof. Lloyd remarks that in the ordinary method, supposing the determination of the horizontal force to be perfect, the limit of error in the determination of the actual force, arising from the error of the dipping-needle alone, is to that in this method in the ratio of the tangent of the dip to unity, so that the latter method is more accurate whenever the dip exceeds 45°. It has been found that with a small circle 4½ inches in diameter, the value of the force deduced from the mean of two or three observations by this method may be depended on with certainty to the third place of decimals inclusive.

We have now obtained all the formulas which are necessary for the determination of the magnetic elements with a complete set of modern instruments. It is not my purpose in this paper to describe these instruments, but it will appear from the preceding discussions that they consist essentially of a magnet horizontally suspended and free to move in a horizontal plane, and a needle vertically suspended and free to move in a vertical plane. We may, however, by further discussion, develop formulas useful, in the absence of one or the other instrument, in the determination of magnetic elements.

Let n represent the number of isochronous oscillations of a horizontal magnet in a given time T. Then by equation (8)

$$n^2=\frac{m\varphi\cos\theta\,T^2}{\pi^2 K} \quad (19)$$

Substituting in this equation the value of $m\varphi$ from equation (2), and solving with

reference to θ, we have

$$tan\ \theta = \frac{wh\ T^2}{\pi^2 n^2 K} \quad - - - - - - - - - - - - \quad (20)$$

a formula which gives the dip θ when the weight w and distance h are known, and the number n of horizontal oscillations, corresponding to the time T, has been counted.

The vertical and horizontal components of the earth's magnetic force, acting upon the points of the needle of inclination in its own vertical plane, are respectively

$$\varphi \sin\theta, \qquad \varphi \cos\theta \cos\alpha,$$

in which α is the magnetic azimuth. Representing the resultant of these forces by φ', we have therefore

$$\varphi' = \varphi \sqrt{\sin^2\theta + \cos^2\theta \cos^2\alpha}$$

Again, representing by θ' the inclination of the needle in its state of equilibrium, and observing that in this case the direction of the needle will be that of φ', we must have

$$\varphi' \sin\theta' = \varphi \sin\theta \qquad \varphi' \cos\theta' = \varphi \cos\theta \cos\alpha$$

whence we have

$$\cot\theta' = \cot\theta \cos\alpha \quad - - - - - - - - - - - \quad (21)$$

and hence

$$\cot\theta = \cot\theta' \sec\alpha \quad - - - - - - - - - - - \quad (22)$$

an equation which will give the dip θ when the azimuth α and inclination θ', out of the meridian, have been observed.

If we represent by θ'' the inclination of the needle in the azimuth $\frac{1}{2}\pi - \alpha$ perpendicular to the first, we have

$$\cot\theta'' = \cot\theta \sin\alpha$$

and, from this and Eq. (21) we obtain

$$\cot^2\theta = \cot^2\theta' + \cot^2\theta'' \quad - - - - - - - - - - \quad (23)$$

a formula which gives the inclination θ by means of the inclinations θ' and θ'', observed in planes out of the meridian and at right angles to each other.

Making $\alpha = 90^\circ$ in equation (21) we have

$$\cot\theta' = 0$$

whence we conclude that if the needle be turned into the plane of the magnetic prime-vertical it will be vertical.

Let us suppose that, in the vertical plane whose magnetic azimuth is α, the inclination needle be caused to oscillate, the amplitudes being small. Designating by n' the number of oscillations in a given time T, we shall have

$$n'^2 = \frac{m\,\varphi'\,T^2}{\pi^2 K'}$$

which is obtained from equation (19) by replacing the horizontal constant force $\varphi \cos \theta$ by the force φ', also constant in magnitude and direction, and the moment of inertia K' relative to the vertical axis, by the moment referred to a horizontal axis perpendicular to the plane of motion. If we successively make $\alpha=0$ and $\alpha=90°$, we shall have respectively $\varphi'=\varphi$, $\varphi'=\varphi \sin \theta$, and designating by i and i' the corresponding values of n', we shall have

$$i^2 = \frac{m\,\varphi T^2}{\pi^2 K'} \qquad i'^2 = \frac{m\,\varphi \sin\theta\, T^2}{\pi^2 K'}$$

whence we obtain

$$\sin \theta = \frac{i'^2}{i^2} \quad - - - - - - - - - - - - - (24)$$

an equation by which the inclination θ of a freely suspended needle may be determined when the number of oscillations i and i' corresponding to the time T, in planes at right angles to each other, have been counted.

At another place or time, if the first of these two numbers be changed to i'' for the same needle, and the force φ to φ'', we shall also have

$$i''^2 = \frac{m\,\varphi''\,T^2}{\pi^2 K'}$$

and consequently

$$\frac{i''^2}{i^2} = \frac{\varphi''}{\varphi} \quad - - - - - - - - - - - - - (25)$$

which proves that at two places, or at different instants, the intensities of the earth's magnetic force are to each other as the squares of the numbers of vertical oscillations of the same needle during equal times, observed in each case in the plane of the magnetic meridian.

This principle seems to furnish a simple method of ascertaining the relative magnetic intensity at different times and places. Indeed until the invention of the statical

method of Gauss, the method of vertical oscillations was very generally employed. Its inferiority will, however, appear upon a closer consideration.

The accuracy of this method evidently depends upon the assumption that the distribution of free magnetism in each part of the needle employed remains constant during all the experiments. I have, however, remarked in another connection, that, even with the best material, the magnetic force gradually undergoes a slight diminution. For this reason, the needle will oscillate slower in the later experiments, and we shall, from these experiments, obtain too small a value for the terrestrial magnetic intensity. If the experiments do not extend over a very long period, and the needle employed is of the best steel and magnetized with care, we doubtless need have little fear of a material diminution of its magnetic power; and if many needles are simultaneously employed, and the greatest of all the results adopted, our determinations will be still less liable to error. Finally, the needles may be brought back to the first station, and their power re-determined; but it must be remembered that this will furnish us with only an approximate and uncertain correction, since the magnetic intensity of the earth is constantly undergoing change. Whatever precautions may be taken, it will be almost impossible to avoid errors due to a gradual diminution of the needle's magnetic power, so that accuracy can be rarely hoped for from its indications.

NOTE TO PAGE 17.

In Eq. (8) the first member, $m \varphi \cos \theta$, is the moment of rotation imparted to the magnet when normal to the magnetic meridian, by the earth's horizontal force, $\varphi \cos \theta$. As we have assumed the foot, grain and second as our fundamental units, it follows that the numerical value obtained for the second member of Eq. (8) expresses the number of units of force which, acting horizontally at the end of a lever-arm of one foot, will balance the above moment. The unit force is that force which can give a unit acceleration in a unit time. If we represent by g the acceleration produced by gravity acting on one grain during one second, our unit force will be $\frac{1}{g}$ grain.

On page 13, we obtained for the moment of rotation exerted by one magnet on the other the expression

$$\frac{2\,m\,m'}{r^3}+\frac{4\,m'\,m_3-6\,m\,m'_3}{r^5}$$

If we neglect the second term of this expression, as we may do when r is very large compared with the lengths of the magnets, we obtain for this moment $\frac{2\,m\,m'}{r^3}$, which is called by Weber the *reduced moment of rotation.* Now let the deflecting magnet be fixed horizontally perpendicular to the deflected position of the suspended magnet and in such a way that the produced axis of the latter shall pass through its centre. For this arrangement it may be readily shown that the reduced moment of rotation is represented by the expression $\frac{m\,m'}{r^3}$. Suppose now that the magnets are equal in every respect; and that they are such that one exerts upon the other the unit moment of rotation, their centres being separated by the unit distance. We then have $m\,m'=1$; and, since $m=m'$, each must equal unity. In other words, that magnet has a magnetic moment equal to unity which, in the position above specified, exerts on a similar suspended magnet, at the unit distance, a reduced moment of rotation equal to that exerted by the unit force acting at the extremity of a lever-arm equal to unity. Hence, the numerical value obtained for m from Eq. (13) expresses, in terms of the above reduced moment of rotation, the effect which the given magnet, fixed as above specified, would exert upon a magnet whose magnetic moment is equal to unity.

The numerical value of $\varphi \cos\theta$ obtained from Eq. (14) expresses the number of units of force which, acting horizontally at the end of a unit lever-arm, would produce a moment of rotation equal to that exerted by the horizontal magnetic intensity of the earth upon a unit magnet in the specified position.

Finally, the numerical value of φ obtained from Eq. (16) expresses the number of units of force which, acting at the extremity of the unit lever-arm, would produce a moment of rotation equal to that exerted by the total intensity of the earth's magnetism acting upon a magnet whose magnetic moment is equal to unity.

NOTES

ON

MILITARY SURVEYING.

READ BEFORE THE ESSAYONS CLUB OF THE CORPS OF ENGINEERS,

APRIL 8 and MAY 6, 1872;

BY

LIEUT. FREDERICK A. HINMAN,
CORPS OF ENGINEERS.

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NOTE.

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F. A. HINMAN,

First Lieut. Corps of Engineers.

WILLET'S POINT, N. Y. H.,

August 9, 1872.

MILITARY RECONNOISSANCES

AND

METHODS OF MEASURING INACCESSIBLE DISTANCES.

A paper read before the "ESSAYONS CLUB" of the Corps of Engineers, on April 8 and May 6, 1872, by Lieut. Frederick A. Hinman, Corps of Engineers.

PART I. MILITARY RECONNOISSANCES.

Topography is a more or less detailed representation, in the form of a map, of a certain area of ground, on a specified scale or proportion of nature, mechanically constructed by the measurement of angles, direct linear measurement, and tangential lines.

The term *reconnoissance* as applied to topography, is a somewhat indefinite one, or rather it might be said it is very comprehensive. When there is any deviation from the closest attainable accuracy in a finished map, it becomes, strictly speaking, a reconnoissance map, and the rudest sketch of a country in which the features are delineated in rough approximation, which for certain temporary purposes is all that is needed, is likewise so called; so that in executing this kind of work, much is left to the judgment of the topographer. The amount of accuracy and closeness of detail required depends solely upon the object for which the survey is undertaken and the time and expense alloted to its completion. It is always best, however, to strive for the greatest precision which the circumstances will allow, particularly as the map may at some future time become available for other objects than that originally intended.

Military reconnoissances relate to surveys which it is necessary to execute very rapidly, either on account of the proximity of the enemy or from other causes, and with simple instruments, or frequently without any. These rapid and irregular surveys having for their object to represent the natural and artificial features of the country, with the maximum exactitude consistent with the rapidity of their execution, it is evident that they are based upon the same principles as are more elaborate operations; the difference between them consisting in the use of more portable instruments, in the substi-

tution of pacing for the use of the chain—indeed, in the estimation of distances and details by the eye in many cases. It is then necessary to have had considerable experience in regular surveys in order to know the most simple mode of procedure and to estimate the errors necessarily introduced.

It is needless to insist upon the importance of military reconnoissances, for a general without an exact knowledge of the local features of the theatre of war, cannot determine upon a plan of attack nor, indeed, undertake any operation of magnitude. When the operations of a campaign are carried on in a country with whose nature, features, and resources a commander is unacquainted, his situation may be compared to that of a man groping in darkness; on the other hand, if he possess an accurate knowledge of the country in which he has to operate, he may act with a boldness and decision that will often insure success. This information is obtained by special reconnoissances, for even the most detailed civil maps do not supply it; they never tell the nature of the soil, the kind and condition of the roads, the state of the rivers and bridges, &c., &c.

MILITARY STATISTICS AND GEOGRAPHY.

By the first of these sciences we understand the most thorough knowledge of the elements of power and military resources of the enemy with whom we are called upon to contend; the second consists in the topographical and strategic description of the theatre of war, with all the obstacles to be encountered, and the examination of the permanent decisive points which may be presented in the whole extent of the frontier or throughout the extent of the country. At the beginning of the French Revolution topography was in its infancy. In 1796 Moreau's army, entering the Black Forest, expected to find terrible mountains, frightful defiles and forests; but was greatly surprised to discover, after climbing the acclivities bordering the plateau near the Rhine, that these were the only obstacles, and that the country from the source of the Danube to Donauwerth, was a rich and level plain. In 1813, Napoleon supposed the interior of Bohemia to be very mountainous, whereas there is no district in Europe more level, after the girdle of mountains surrounding it has been crossed, which may be done in a single march. The recent war has shown in a forcible manner how little accurate information there was with respect to the topography of the interior of many of our western and southern states.

Military statistics are not much better known than geography, we have but vague and superficial statements, from which the strength of armies and navies and the revenue possessed by a state are conjectured; which is far from the knowledge necessary to plan operations.

Nothing should be neglected to acquire a knowledge of the geography and military statistics of other states; by multiplying the means of obtaining information, no matter how imperfect and contradictory they may be, the truth may be sifted from them, but perfect reliance should be placed on none.

QUALIFICATIONS OF A RECONNOITRING OFFICER.

Military reconnoissances are usually made by staff officers. The lattter are sent during peace to study the countries that may become theatres of operations, and to draw up descriptions of them, by means of topographical maps, if they are permitted; if not by memoirs, at the same time making note of any errors that they are able to discover in existing charts. It is the staff officer, too, who protected by a few troops, makes in the presence of the enemy the sketches which represent the most essential features of a position; he, also, prepares the itineraries as the army advances, surveys battle-fields and often large extents of country.

From the services demanded of a reconnoitring officer, it is important that he should possess acquirements of a very high order in the departments of geography and statistics; to which must be added a minute acquaintance with topography, and a good *coup d' œil militaire* for that of the latter. He should know what space is required by a battalion, by a squadron, and by a battery in their different formations, and the average time required for certain movements, under given circumstances of ground. It is indispensable that he should speak the language of the country in which he is to act; he must be cool-headed and *truthful*—see things as they are, and tell clearly and precisely what he has seen, separating what he knows from observation, from that which he has learned from others, and add all the circumstances of time and place with accuracy. Distinguished officers should be employed in these scientific labors and they should be rewarded when they acquit themselves with credit.

It is evident that, in the performance of these duties, the man who is merely a student, however intellectual, will be very inferior to the shrewd and ready observer who has developed in various pursuits his ingenuity and resources. The staff officer may bring diversified knowledge into effectual play, some acquaintance with *geology* may enable him to recognize at once the character of whole tracts of country, discerning whether they are boggy, gravelly, rocky; what sort of roads may be expected in them; what resources they will afford; and whether field-works will be easy or difficult of construction. Without being a learned *botanist*, he may often recognize the nature of the soil or of a ford from the character of the herbage. He will find a knowledge of the influence of *climate* upon soil, upon the rise and fall of rivers, and upon crops, of great value. A

knowledge of *meteorology* will be of great assistance to him, thereby enabling him to understand the signs which indicate storms, heat, or sudden changes. A knowledge of *signalling* and *photography* &c., will also be of great use.

Staff officers who join acquirements to ability and a spirit of enterprise are the springs which, directed by sagacious generals, impart order, force, and purpose to the machinery of armies.

PRELIMINARY DUTIES.

The first thing to be done by an officer is to ascertain *precisely* the duty required of him; and what further should be done in case of certain contingencies that may, from the nature of the duty, be naturally looked for. He should provide himself with maps, a good telescope and such simple aids for judging of distances, and ascertaining the relative positions of objects, as he can readily make or obtain; writing materials; one or more good guides (if required) and gain all the knowledge he can from the inhabitants at hand bearing on his mission.

Before however proceeding to make a reconnoissance, a careful inspection of the general map of the country will facilitate, and may greatly abridge the labors of the officer. This will be sufficiently evident when it is considered—1st, that the water-courses are necessarily the lowest lines of the valleys through which they flow, and that their direction must also be that of the lines of greatest declivity of their respective valleys. 2nd, that from the position of the water-courses the position also of the high grounds by which they are separated naturally follows, as well as the approximate position at least of the ridges, or highest lines of the high grounds, which separate their opposite slopes, and which are at the same time the lines of greatest declivity common to these slopes, as the water-courses are the corresponding lines of the slopes that form the valleys. Keeping these facts (which are susceptible of rigid mathematical demonstration) in view, it will be practicable, from a careful examination of an ordinary general map, if accurately constructed, not only to trace, with considerable accuracy, the general direction of the ridges from having that of the water-courses, but also to detect those depressions in them which will be favorable to the passage of a communication to connect two main or two secondary valleys.

The following illustrations may serve to place this subject in a clearer aspect:—1st, if it be found that on any portion of a map the water-courses seem to diverge from or converge towards one point, it will be evident that the ground in the first case must be the common source of the water-courses, and therefore the highest; and in the second case that it is the lowest and forms their common recipient. 2nd, if two water-courses flow in opposite directions from a common point, it will show that this is the point from which

they derive their common supply, at the head of their respective valleys, and that it must be fed by the slopes of high grounds above this point; or, in other words, that the valleys of the two water-courses are separated by a chain of high grounds, which, at the point where it crosses them, presents a depression in its ridge, which would be the natural position for a communication connecting the two valleys. 3rd, if two water-courses flow in the same direction and parallel to each other, it will simply indicate a general inclination of the ridge between them, in the same direction as that of the water-courses. The ridge, however, may present in its course elevations and depressions, which will be indicated by the points in which the water-courses of the secondary valleys, on each side of it, intersect each other on it; and these will be the lowest points at which lines of communication, through the secondary valleys, connecting the main water-courses, would cross the dividing ridge. 4th, if two water-courses flow in the same direction, and parallel to each other, and then at a certain point assume divergent directions, it will indicate that this is the lowest point of the ridge between them. 5th, if two water-courses flow in parallel but opposite directions, depressions in the ridge between them will be shown by the meeting of the water-courses of the secondary valleys on the ridge; or by an approach towards each other, at any point, of the two principal water-courses.

OBJECTS TO BE REPRESENTED.

To designate all the objects to be represented in a reconnoissance would be almost impossible. A general view of the ground to be examined must first be taken in, so as to obtain some idea of the forms of the parts, their connection and relations to each other, before going into a detailed examination. The survey is commenced by the determination of a base, and the principal lines by triangulation, to which details are afterwards referred, all then reduces to angles and a base; the latter may be taken from a general map or obtained by the chain or by pacing. The general study of the country will not demand much time; a level country, for example, is usually well cultivated, and therefore has hedges, ditches, fences, etc.; in a mountainous one are dangerous passes, torrents with rough beds, etc. Every feature demands a particular examination and the report should show its advantages and disadvantages. It is very useful for a staff-officer to consider what observations he may with most advantage *habituate* himself to make, so that, under all conditions of ground, he may recognize the essential features, which will now be briefly enumerated. *Roads.*—Their width; which ought to be twenty feet, for free and convenient passage of troops. The minimum width for an emergency must be determined by the space required for the passage of a gun. Whether they pass over good or bad bottom; whether easily reparable, and if materials for mending them exist near,

such as fences, stone-walls, brush-wood, straw, reeds, etc., etc. Contractions of the roads, such as fords, bridges and defiles; width, material, and strength of bridges. The foregoing particulars are necessary for all movements in an imperfectly known district; for example, when a combination is to be directed from all quarters on a particular point; as in marching to engage the enemy.

If movements are to be made near an enemy, it must also be noted where the road is commanded; what positions it affords in case the march should be opposed; what roads and paths fall into it, and their directions; where it is bordered by trees, hedges, ditches, stone-walls, or marshes; and the nature of the slopes on each side of the bridges, or fords, with regard to attack or defense. When parallel roads are near, the nature of the ground and communications between them, should be investigated.

Rivers.—Character of banks; of fords; freshets; points where bridges may be built; whether the rivers freeze entirely, or in part; sites for batteries for protection of bridges. Rivers which wind and form many bends in their courses, offer more facilities for effecting a passage than those which run direct; since to prevent the passage the enemy has to move on arcs, while his opponent has only their chords to traverse.

Woods.—The kinds of trees composing them; whether adapted for abatis; whether the trees are wide apart, permitting cavalry to penetrate, or thick and difficult to traverse, and whether the wood would be an advantage or a hindrance in case of taking position in it or near it.

Defiles.—Their lengths; whether their gorges are open or narrow; mode of occupying them to cover a retreat; how to distribute troops both to attack and defend them, and whether they can be *turned* if strongly occupied.

Mountains.—Chains of mountains are the best barriers of a country; there are but few roads among them and their valleys alone are inhabited and practicable. Mountainous and hilly countries, partly cultivated, partly wooded, are the most difficult and tedious to reconnoitre correctly; because on all sides they afford positions of which there are very few not liable to be turned. They cannot, therefore, be too closely and accurately reconnoitred.

Defensible Positions should be looked for at proper distances for halts and encampments, with wood and water at hand.

Railways.—The lengths of embankments, tunnels, and cuttings should be noted; embankments may form a commanding position for artillery if the front be clear. Also, the capacity of railway carriages; and the speediest means of filling and emptying them of troops and horses, not only on the platforms of stations, but on other parts of the line, as Jackson's troops quitted the train on the field of Bull Run. The *towns*, *villages*,

hamlets, *country-houses*, *churches* and *farms*, etc., should all be described.

Fortifications.—Permanent or temporary, low or high; if reveted with stone, brick or sods; natural or artificial, old or new; the defense of which they are capable, etc.

Coasts.—Their character; nature of harbors, etc.

Reports are generally divided into four parts; 1st, the physical description; 2nd, the statistical; 3rd, the communications; 4th, military considerations.

KINDS OF RECONNOISSANCES.

In actual service reconnoissances are of three distinct kinds; 1st, those made on foot with a pocket compass, a protractor and a hand level, often combined with a plane-table and chain; 2nd, those made on horseback with a pocket compass and a watch. (For both, a pocket sextant is a most useful addition to the outfit.) 3rd, those made with the camera.

The usual method employed during the late war was as follows: When the army was stationary, or moving leisurely, one main road was run with the plane-table, the operator being accompanied by assistants well practiced in the use of the compass. Upon arriving at any important road or water-course, assistants were sent to the right and left, starting from plane-table points, determined by the chaining, and running as far as requisite, then returning to the main road again to repeat the operation, the compass notes of course being kept in a book prepared for the purpose. Prominent points determined by the plane-table were used as checks in the compass work. The intervening topography, where no compass or plane-table work had been done, was sketched in by the chief of the party, in which accurate pacing became of great value. In the siege of Yorktown a plane-table survey was made parallel to our trenches, and as near them as practicable, and foot reconnoissances were then made to the front from points whose relative positions were accurately known.

FOOT RECONNOISSANCES.

These reconnoissances are usually made within the outposts. The best *compass* for this purpose is the one issued from the office of the Chief of Engineers, consisting of a good needle mounted in a square wooden box three inches on the side. It is graduated continuously from zero to 360 degrees, the north and south line being parallel to the side to which the cover is hinged. The field box-wood *protractor*, also issued from the office, is designed to so facilitate the plotting of the compass bearings as to permit the map to be made upon the spot like a plane-table sketch. It is graduated from zero to 180 degrees on the one side and from 180 to 360 degrees on the other, both marked from left to right. A scale of tenths of inches is marked on both sides

and connected over the edge of the border containing the centre; the following is the method of using it with the compass above described:

Open the compass cover on its hinges until it makes about a right angle with the plane of the needle. Hold the box horizontally in one hand and the cover vertically in the other. Sight along the top edge of the cover towards the north and note the end of the needle which points towards the south—this is the index end which must always be read in taking bearings.

To take a bearing hold the compass as above described, the needle at the height of the chin; lower the head a little and sight along the top edge of the cover to the object; touch the finger occasionally on the catch to make the needle settle quickly; when it becomes steady raise the head without moving the hands and note the reading in the degrees indicated by the index end of the needle. This is the desired bearing.

To record the work provide in lieu of a note-book, a sheet of paper ruled in one direction, and attach it to a light drawing board; mark the paper so that the rulings shall be meridians, the top being north; knowing the general direction of the proposed reconnoissance, select the starting point on the paper so as to bring the plotting within its limits; lastly, *plot all bearings* as follows:

Turn the side of the protractor on which the reading of the needle is found, upward; place the centre on one of the ruled north and south lines passing near the point marking the station; place the compass reading on the same line, towards the north; slide the protractor with these two points always on the same north and south line until the edge passes through the point marking the station; draw a pencil along this edge in the right direction—which is always known from the compass readings of the borders of the paper—and the bearing is plotted.

Distances on the trail are determined by counting steps, and the map should be plotted in this unit. The exact length of step should be determined by trial over a known course. The *scale* should be about five inches to the mile, one tenth of an inch (the smallest division on the protractor) being assumed to represent forty paces. Besides the trail itself, all prominent objects should be accurately located by bearings, judging by the eye of their position respecting the points fixed by triangulation. Undulations are marked after the sketch has been thus far finished; the *contours* being traced with the hand-level. A spot is selected near the lowest point of the survey for reference zero, and a course is run up the steepest hillside bordering it. Standing at the bottom, the level indicates where the plane of the eye intersects the trail on the hill-side; standing at this point, a second sight marks with sufficient exactness the ten foot curve upon the part of the ground in sight, and it should be at once drawn upon the corresponding

portions of the map, judging of its location respecting known points, by the eye. Repeat the operation until the hill-top is reached; and then extend and continue the work by making other similar sections, until the contours are traced over the entire map. Sometimes it is convenient to establish bench-marks with the Y level in order to check the work.

RECONNOISSANCES ON HORSEBACK.

These reconnoissances are usually made beyond the outposts, in the vicinity of the enemy, with a strong escort of cavalry; and the essential condition is that not a moment shall be wasted, nor the march of the column be delayed. It is not usually practicable to dismount to take bearings, and field-plotting of course cannot be attempted. The officer must enter in an ordinary note book such approximate bearings of the trail and of prominent objects as he can secure from the saddle, and such a sketch of the vicinity of the route as can be made by the eye. His pace should be as uniform as possible, when practicable the whole survey should be made either on a walk or on a trot, so as to avoid errors resulting from a combination of gaits. The distances should be noted and subsequently plotted in time. All points of military interest should be noted. Thirty miles ought to be mapped in a day. The plot must be made in the office, using the protractor as already described. In constructing the *scale* on the map, the gait of the horse must be regarded; a scale of two inches to the mile will usually represent the field-notes with all attainable accuracy. If one-tenth of an inch be assumed to represent one minute on a walk, and one-half a minute on a trot, the resulting map will not differ materially from this scale.

OFFICE WORK.

Usually great dispatch is required in finishing sketches in active service. The simplest method of so doing is to draw a *red* and *blue* pencil over the roads and streams, respectively, and to add a flat tint of *blue* for lakes and of *green* for forests. Important information not easily represented, should be written on the map in form of notes. In fifteen minutes of office work a whole day's sketching may thus be transformed into a map which, although not elegant is exactly what is wanted in a military survey. An accustomed eye with the map in hand would not discover any marked discrepancy. The *scale* upon any map should consist of a double line (the lower being the heavier) divided into suitable units of length and numbered from zero placed at the right hand end of the left division—which division should be sub-divided decimally, the heavier line being omitted. The value of the unit should always be noted.

THE APPLICATION OF PHOTOGRAPHY TO MILITARY RECONNOISSANCES.

The applications of photography to warlike purposes are numerous and various. There have been few adaptations of this beautiful art to military purposes, beyond that of copying, enlarging, and reducing maps and plans. In connection with the production of surveys, the engraving of maps, the copying of designs, the registration of service patterns, the recording of experimental results, the instruction of troops, the controlling of work performed, and in other directions too numerous to mention, photography is employed. The faithful accuracy with which the art fulfills its functions, causes its aid to be eagerly sought for in any way where it can be made available. Not only, however, does the employment of the camera recommend itself on the score of fidelity, but likewise by reason of the very inexpensive nature of the results furnished, and the degree of facility with which they are obtained. From the fact that they are invariably absolute copies of the originals, reproductions obtained by means of photography must always be endowed with a certain value, while in many cases, where it would have been impossible to have secured pictures by any other means, the results of the camera are simply priceless.

The first time that photography was used in connection with military matters was during the Crimean war. Since that period the art-science has progressed to a wonderful degree, so much so, indeed, that we cannot but anticipate its speedy and complete perfection. In the capacity of multiplier and printer of maps, orders, circulars, etc., the aid of the photographer is invaluable. If a large issue of copies is required immediately, several negatives are at once taken, and these, consisting simply of opaque glass with transparent lines, are easily and rapidly printed. The maps are printed upon paper then cut into squares and mounted on linen, so as to fold without injury. By a new process maps can be photographed directly on linen or rubber cloth, thereby saving much time and making the maps more durable for field service.

Besides, however, the question of obtaining pictures of points of interest for subsequent preservation and record, landscape views taken judiciously might be made to render great aid to an army in the field. The time and trouble involved in obtaining these pictures would be very trifling. An officer attached to the reconnoitring party could easily carry the two packages necessary for the purpose; one being the camera and the other a couple of plate-boxes. The camera might be provided with a lens, which should always be in focus, or, inasmuch as pictures would generally be taken at some considerable distance, an ordinary lens might be used, the focus of which has been adjusted to an object distant one hundred times the focal length of the instrument; for it has been

found that a lens thus focussed, yields a very clear definition of any object beyond the distance mentioned. The camera, therefore, has merely to be set down in the direction in which the view is to be taken, a glance being all that is necessary to ascertain that the picture required is that depicted upon the screen; the case containing the dry prepared plate (of which more anon) is slipped into the camera, the glass exposed for a given period, according to circumstances, and then returned to its former position. This is all that need be done. Any one would require but a few minutes' instruction to be able to take three or four pictures in this manner within a quarter of an hour. On returning to camp, the plates are handed over to the photographic staff, with an intimation of the length of time they were exposed to the light, and the negatives would then be developed, and printed in the ordinary manner. These field pictures should, as a rule, be of small size. A small camera is better than a large one as it is more easily worked, and with much less risk of failure; its action is always rapid and often *instantaneous*, a quality of great importance; it involves less expense, less bulky apparatus, and less skill in manipulation; and, furthermore, the pictures produced by it may subsequently be enlarged to any desirable size.

The class of subjects fitted for instantaneous exposures is limited to that wherein there are no violent contrasts of light and shade. Foliage combined with clouds, can hardly be rendered with good effect by the same amount of exposure, for while the former may be secured almost instantaneously, the latter, under the most favorable circumstances, take an appreciable time to affect the sensitive plate. Moving objects in the foreground must be avoided.

The time selected for operating should be when the weather is warm and the light of the most actinic character. The former under all circumstances promotes energetic action of the chemicals; the latter condition can only be accurately ascertained by experiment at the time. A clear atmosphere with light fleecy clouds (known under the name of the mackeral-back sky) in the zenith, and banks of cirro-cumulus in the horizon, combined with a gentle south-west breeze, are almost always conditions of the highest actinic power in the light. A cloudless sky with haze in the distance, are indications of the opposite kind.

The important advantages accruing from the use of *dry-plate* photography in the field, are very obvious. The large, cumbersome, dark tent, the stock of chemicals and utensils, the apparatus required for the preparation and development of the negative, are all unnecessary, the camera, stand and plate-box, or two or three dark slides, being all that are required. The manner in which plates of this kind are produced is very simple. A sheet of glass is coated with collodion and dipped in the silver-bath in the ordinary

manner to render it sensitive; after being thoroughly washed, a preservative solution is poured over the surface, and when it has again been rinsed and dried, the operation is finished. The degree of sensitiveness possessed by a dry plate, and the period of time during which it retains this sensitiveness, depends principally upon the nature of the preservatives used, and also upon the care exercised in preparing the plates. Substances of almost every description have been used as preservatives—tannin, honey, coffee, tea, gum, albumen, morphine, syrup, etc., etc. The gum process of Mr. Manners Gordon is preferable when sensitiveness is the main point to be observed, the coffee of Col. Baratti, when it is likely that a long time may elapse before the employment of the plates, the latter have been known to retain their sensitiveness for a period of fifteen months; at the same time it is well never to use dry plates more than a month old.

CHEVALIER'S APPLICATION OF PHOTOGRAPHY TO MILITARY RECONNOISSANCES.

This method consists in taking small circular pictures, or panoramas, round each station of the triangulation into which the survey is divided. These panoramas are printed by the ordinary photographic method, and are cut out and fastened on a sheet of drawing paper in the relative position to each other which they occupied on the ground to be surveyed; and straight lines or radii being produced from the centre of each through the objects shown in them, give by their intersections the relative position of each object on the paper, so that the "filling in" is completed as rapidly as these intersections can be formed. This method possesses many advantages over the other methods of surveying, since it dispenses with the slow process of observing each object separately, and the liability to any possible error in recording the observations in the field-book, which is now quite dispensed with.

The camera (Fig. 1.) consists of a cylindrical box similar to the prismatic compass, the card in the latter being replaced in the former by a circular plate of glass previously sensitized by the dry process, which takes a picture almost *instantaneously*; the cover of the camera (not shown in the Fig.) revolves loosely on it, and carries the lens, which is combined with a prism, so as to produce a horizontal picture on the glass, of any object in front of the lens: as the top of the box and the lens are made to revolve around its vertical axis, a continuous annular picture or panorama is produced on the glass below, and of course retained by the sensitive film. The glass is removed, developed, fixed, and printed on paper by the ordinary photographic method, and the picture, as before remarked, transferred to the drawing-board in its proper position.

One great advantage of this method is, that as the pictures accompany the plan, the commander, for whose information it is intended, has these panoramas of the country

actually before his eyes, and can thus form an infinitely better idea of the ground, than can be conveyed to him by any other system of delineation, however careful or accurate; and another is that very little drawing or filling in is really necessary, as the pictures supply all the inner details, and all that is necessary is to show the intersections of the lines through the principal objects. Of course the use of this method would be to a certain extent limited by the small size of the objects shown in the panoramas, and we must still have recourse to the ordinary method of making grand geodetical surveys, where the sides of the triangles are sometimes a hundred miles in length; but for a reconnoissance of an intended field of battle or of a fortified position, even occupied by an enemy, this method will be invaluable.

Fig. 2 represents a sketch of the panorama after it has been printed. The circle represents the horizon line, and by drawing lines from the centre through the different objects we have all the angles around the station. A, B, C and D, (Fig. 3.) are panoramas cut out and pasted on the paper. Of course it would be necessary to measure one side, as A B, for we must have a base to give us a scale.

Two mounted officers, furnished with these cameras, might gallop from a given point, such as a tree (Fig. 4.) counting the paces of their horses, and diverging from each other as they advance to the front of a position, even within range of an enemy's guns, and each take a panoramic view from the extremities of a line, A B, and be off again before the fire could open on them; as they would know their distances from the point from which they started, they would bring back with them a complete plan of the position. Fig. 5 shows the application of the instrument to taking vertical angles. In this case the instrument is turned down on one side on its ball and socket joint. The box becomes vertical and the tube horizontal. Then, as the cover is turned around, the whole of the picture represented in the Fig. would be taken. A B is the horizon and D represents the station or any white object placed under the box as a mark. Clouds are shown as they would be seen directly from underneath. Altitudes of the sun etc., or birds on the wing can also be taken. The direction of the magnetic meridian can be shown in the following manner: put a pocket compass on the box and send out a man to any point, in the proper direction near the horizon, to hold up a white staff; when the picture has been taken he will be represented in it with the staff, the latter being in the direction of the magnetic meridian.

BAILLIE'S APPLICATION OF PHOTOGRAPHY TO MILITARY RECONNOISSANCES.

It has been shown how it is possible to make a survey of an enemy's position, even under fire, by the aid of photography; but this plan involves certain conditions which

can rarely be secured. It could not be carried out, for instance, if the enemy covered his line with advanced videttes of cavalry or pickets of infantry, as he ought to do, when not liable to momentary attack, so that to obtain a photograph of his works it might be necessary that the videttes and pickets should be driven in, which we could generally do with an inferior force, or sufficiently so as to enable us to get a good view of his lines. The photographic party should accompany our skirmishers, and get well in front, so as to have a good view; it therefore becomes a question as to what kind of apparatus should be used for the purpose. We cannot find a better model for the apparatus than a light gun and limber, with a well trained squad of real gunners to take the photographs. A gun-carriage is as firm and portable a stand for a camera as we can possibly produce, and the elevating screw would enable us to point it as quickly as a gun. The limber-chests would contain any number of prepared plates, each in a separate box. With cool operators, the camera could take a picture for every shot from the gun beside it. The camera could be made to resemble a gun, so that it might take up its position with the guns on their windward flank, so as to be taken for one of them, and thereby attract less attention. The only non-mechanical part of the photographic process is the focussing and timing of the exposure, and the last is simplified by using one of the instantaneous processes.

These photographs need not be printed on paper, unless it is desirable to obtain copies of them for record. On the contrary, it would be sufficient to use what is called a "positive" process, which, when backed by black varnish, gives a picture distinct enough for all ordinary purposes. A commander having several of these cameras at his disposition, would literally have his eyes everywhere. He could be supplied with these optical reports from each division of his army as fast as orderlies could carry them, and it would be possible for him to remedy with them the defects of his own short-sightedness. It has been said that the camera should be constructed to resemble a gun; it is believed that it is quite possible to convert the long tube into a telescope, and so obtain pictures at a range equal to that of the gun itself. It is not known how far the loss of light in such pictures might weaken its impression on the sensitized plate, but there is no doubt that some "process" could be supplied suited to the purpose, in the meantime, we know that any photograph, carefully focussed, will bear very considerable enlargement in the magic lantern, and the details even of the extreme distances will be faithfully reproduced, though so small as only to be visible with the microscope.

PART II. METHODS OF MEASURING INACCESSIBLE DISTANCES.

In the foregoing operations, as well as in artillery and torpedo service, it is often necessary to measure distances of objects not accessible to the reconnoitring officer. This question appears to be of sufficient importance, as to justify a somewhat detailed account of the different ways in which it may be accomplished.

The simplest mode which suggests itself for determining the distance between two points of the earth's surface, is to apply a measure of known length along the line connecting them. This is the method used in common surveying. It admits of a near approach to accuracy when the inequalities of the intervening ground are inconsiderable, and the measuring instruments accurate. But great care and skill are necessary, even under these circumstances, in order to preserve the line direct and to insure the commencement of each successive measurement from the exact point at which the last one ended. Over broken ground, water-courses, lakes, and mountainous districts, direct measurement is always attended with great difficulties, and is often impracticable. For geodetic operations of importance it is, therefore, usual to call in the aid of trigonometry. Direct measurement is still necessary, even in this case, in order to establish a base for the commencement of operations; but the ground upon which this base is measured may be chosen at pleasure, and need not even be in the vicinity of the line or the surface of which the dimensions are required. After the base has once been measured—a process which in large works of geodesy is a very small part of the whole, but one which must be executed with all care and deliberation—the remaining field-work is reduced to the observation of angles; in the performance of which, instrumental accuracy has been carried to an extraordinary degree of refinement.

As before remarked, there are many purposes for which it is desirable to measure *inaccessible distances*, with something less than absolute accuracy, yet more accurately and expeditiously than they can be measured directly. To accomplish this object a variety of instruments have been devised, some of which will now be described; as well as the various methods of ascertaining the widths of water-courses; how to determine the distances between points in an enemy's line of works; points along the line of march; how to determine ranges; to locate torpedoes; etc., etc.

It is here remarked that it would be quite impossible to work any system of defense by torpedoes, or any of the more delicate modes of determining the distances of ships in motion, involving simultaneous observations from distant extremities of a long base, to advantage without a well devised system of electric apparatus.

When an object at a distant station and visible to the observer is of known dimensions, this problem presents comparatively little difficulty. Any instrument by which angles may be accurately measured will suffice to resolve it. If the two stations are on the same level, it will only be necessary to measure the angle at the observer's eye subtended by the object; and this being ascertained, a triangle will be given in which all the angles and the base are known. If the stations are not on the same level, or nearly so, it will be necessary, additionally, to measure the angle of elevation or depression of the object observed. The distance sought, however, can only be found by this process, by means of a solution of the triangles obtained as above, and this involves a somewhat troublesome numerical operation. The necessity of such a calculation may be avoided by the preparation of a table in advance, in which angles may form the arguments at the side, while the various possible linear dimensions of objects observed, may furnish the arguments at the top. The distance corresponding to any given object and angle may then be found by inspection. It is convenient, nevertheless, to be relieved of even the necessity of consulting tables, and this may be done by graduating the instrument itself in such a way that, after any observation, an index shall point to a number telling the distance; as in the case of the *Stadia*, or to a number telling how many times the distance is greater than the object.

Rochon's Double Image Telescope is an instrument of the latter description; that is to say, its indication multiplied by the known dimension of the object gives the distance; but it is not what we have been supposing above, an angle-measuring instrument. The instrument may be graduated by theory, but it is better to determine the scale by trial.

The *Binocular Telemetric Marine-Glass* is designed to determine distances by measuring the angle subtended by a known object; and this by a construction which permits the axes of the two tubes to be thrown out of parallelism by an angular movement around an axis joining the two eye-pieces. The effect of this is to double the image of an object, which appears single when both axes are in the same plane. One of these images will appear directly over the other, and when they are in contact by their edges, the angular movement of one tube which has been required to produce this effect will be, of course, equal to the angle subtended by the object at the eye of the observer.

The *Stadimeter* or *Telemeter* is a horizontal rule bearing strongly marked divisions, which are numbered from the centre in both directions, the whole being supported by a vertical rod. The marks are in white on black for the sake of greater distinctness, and the numbers are inverted that they may appear upright in an inverting telescope.

In the focus of the eye-piece are two fixed micrometric lines, and the determination of distance is made by observing how many divisions of the Stadimeter are embraced between these lines. (See "Coast Survey Report"—1865, for manner of using this instrument, etc., etc.)

Telemetric Double Telescopes.—For the determination of distances by means of observations upon objects whose dimensions are unknown, it is necessary in general to obtain a parallax, or angle subtended at the distant station by a base at the point of observation. Instruments have been constructed with two telescopes fixed at the extremities of a bar or rod of determinate length, one of them being movable in azimuth over a divided circle, while the other is fixed, when the index of the movable telescope is at the zero of the graduation, the two axes ought to be parellel. If then both telescopes are directed at the same distant point, the parallax may be directly read. (For illustrations and methods of adjusting the above mentioned instruments, see Barnard's Report of "Paris Universal Exposition"—1867.)

The Plane-table.—This instrument is used in determining the lines of a survey, both in extent and position. Having placed a paper on the table, examine the objects and lines which are to be represented, and select for a base a convenient portion of such a line, that most of the objects can be seen from its extremities. Then, place the plane-table with its centre, nearly, though not accurately over one extremity of the base; make it truly horizontal, and turn it until the larger part of the paper lies on the same side of the base with the objects. Then, tighten the clamp screw, and mark with a pin the point of the paper directly over the station, which point is determined most accurately by suspending a plumb from the lower side of the table. Press the pin firmly on this point, bring the fiducial edge of the ruler against it, and sight to the other end of the base line, and mark with a pin or pencil, the direction of the line on the paper. Sight in like manner to every other object, and draw on the paper the corresponding lines, numbering them from the base line, 1, 2, 3, 4, etc. Then, with a pair of dividers, take from the scale a certain number of equal parts to represent the base, and lay off the distance on the base line from the place of the pin. Take up the table, carry it to the other extremity of the base, and place the point of the paper corresponding to that extremity, directly over it. Place the fiducial edge of the ruler on the base line, and turn the table, by means of the tangent screw, until the sights are directed to the first station. If, however, in bringing the table to this position, the corresponding point of the paper has been moved from over the extremity of the base line, move the legs of the tripod until it is brought back to its place. Let the table be then levelled, after which, place the ruler again on the base line, and bring the table to its proper position

by the tangent screw, and continue the adjustment until the extremity of the base line on the paper is directly over the station, and in the same vertical plane with the base line on the ground. Then direct the sights to all the objects sighted to from the other station, and mark the lines 1, 2, 3, 4, etc., from the base line as before. The intersections of the corresponding lines 1,1, 2,2, 3,3, 4,4, etc., determine, on the paper, the positions of the several objects; and a reference of these lines to the scale of equal parts, determines the true distances. The principal use of the plane-table is for the interior filling up of trigonometrical surveys; it is also used with advantage, for determining ranges and in reconnoitring an enemy's lines, it should not, however, be used for the determination of long lines. (See "Coast Survey Report"—1865, for an interesting account of this instrument.)

The *Stadia* consists of a piece of copper, or other material, with an isosceles triangle cut out of it, the upper and lower sides are graduated, and a slide works from left to right. The base of the opening is perpendicular to the sides of the instrument, and, when intended for infantry, represents the apparent height of a man at a given distance, when the instrument is held horizontally at a certain distance from the eye. In order that the instrument shall always be used at the same distance from the eye, a string or chain is attached to the slide. The graduation of the sides of the instrument is made by observation or calculation, assuming the average height of a man to be a certain number of inches. The upper side may be graduated to determine the distance of foot-soldiers, the other the distance of cavalry. In the latter case, we must regard the top of the trooper's cap and his horse's feet. To use the instrument, hold the knot at the end of the string between the teeth, stretch the string by extending the arm, keeping the base of the opening vertical; pass the instrument from right to left across the field of sight, until the top and bottom of the object appear to graze the sides of the opening respectively. Move the slide to the point of apparent coincidence, and take the reading above or below, as the case may be. This will give the distance.

Electric Position-Indicator, or *Distance-Measurer*.—This apparatus is intended to indicate at any moment, the position and distance of any vessel or other moving object within a certain range. It operates in the following manner: (Fig. 6.) Two telescopes, F_1, and F_2, are firmly placed at a certain known distance, A B, from each other, which is called the base; these telescopes are directed by two observers upon the object whose position is to be determined, so as to bring and keep it upon the vertical cross-wire of each. The telescope F_1 moves over and parallel to a plane-table M, upon a vertical and rigid axis A, and carries with it a ruler l_1, the *right* edge of which cuts the axis A, and which slides upon the plane-table, and shows thereon the direction from A

to the observed object. A second ruler, l_2, to the right of the other, moves upon a similar axis, b, at a slight elevation above the plane-table, (equal to the thickness of the first ruler, l_1,) and has its *left* edge cutting through the axis b. In placing the apparatus, the plane-table M must be so adjusted that the line connecting the two axes A and b shall coincide with the base A B; and to obtain and secure this adjustment, a mark made for the purpose on the other apparatus, B, must be brought and kept under the cross-wires of a small telescope, F_3, which is fastened to the plane-table with its optical axis parallel to A b. In order to change the elevation of the telescope F_1, the whole apparatus is made movable at a small angle, upon an axis (not represented in the figure) parallel to A b, without interfering with the adjustment by the telescope F_3.

If now a distant object, C, is sighted simultaneously by the two telescopes F_1, and F_2, it is required to cause the ruler l_2 to take a direction parallel to the optical axis of the telescope F_2, in order to make the two triangles A B C and A b c similar to each other; when the distance from A to c, the point where the right edge of the ruler l_1 is crossed by the left edge of the ruler l_2, will be in direct proportion to the distance A C; and A C = (A c × A B) ÷ A b. Therefore, if a chart of the surrounding area be adjusted to the plane-table, so that the points A and b shall represent respectively the positions of the two telescopes F_1 and F_2, the point c, where the inner edges of the two rulers cross each other, will show upon the chart the exact position of the object C.

The requisite adjustment of the ruler l_2, parallel to the telescope F_2, is effected by electric power, simultaneously with the sighting of the object C through that telescope. The observer at B points his telescope, F_2, at the object C, not by simply moving it in the customary way, but by turning a crank with an endless screw, which acts upon the teeth of a circular segment attached to the axis of the telescope. In doing so he also causes, by couplings, the anchor of a magneto-electric current-generator to rotate quickly. The currents generated in the coils of the latter are, by two conducting wires stretched between the two apparatus, carried to A, and act there through an electro-magnetic apparatus, constructed for the purpose, on the ruler l_2, in such a manner as to move it in the same direction and with the same rapidity as the telescope F_2, is moved, by turning (ahead or back) the crank through the endless screw. The telescope F_2, and the ruler l_2, therefore, if once adjusted parallel to each other, remain so throughout the operation by the action of the currents. For this parallel adjustment, the two apparatus must in the first place, be adjusted with each other by means of the two small telescopes F_3 and F_4, and securely fixed in position; after which the telescope F_2 and the ruler l_2 are laid parallel to each other by means of marks cut upon the stands of their respective apparatus before the magnetic connection is made. (This ad-

justment could be made by means of compasses when the stations are not in sight of each other.) It is evident, from the foregoing, that the course of the moving object C, if steadily kept under the cross-wires of the two telescopes F_1, and F_2, will be represented on the plane-table projection M by the successive crossing points of the inner edges of the two rulers l_1 and l_2.

In order to be able to designate at any time by figures the position of the crossing point of the two rulers, (or, in other words, of the object C,) for the purpose of communicating it to other parties, (forts,) the entire face of the plane-table, or chart, is divided into numbered squares of suitable dimensions. These numbers are communicated to another fort, by means of a magneto-electric dial apparatus, as such does not require a battery; which is also avoided in the distance-measurer. In order that the fort may be able to ascertain the position of the object C from the number so communicated, it must also be provided with a chart of the locality, upon which its own position is marked, and the same squares and numbers are shown as on the plane-table of the distance-measurer.

The object may thus be found on the chart by the number, and its distance from the fort measured on the scale of the chart. It will be found convenient to mark this scale upon a strip of tin, which shall be movable around a pivot at its zero point, and fastened thereby at the point of the chart which represents the fort. This movable scale will only need to be turned over the communicated number, and the distance can be read off directly; or a table might be prepared giving the distances corresponding to each number.

The distance of the object C from A, in linear measure, might, so long as the two rulers cross each other, be read on a scale engraved on l_1; but as it is frequently of importance to know the linear distance when, on account of the greater distance of C, the two rulers do not cross each other, the following mechanism has been provided: (Fig. 7.) A third ruler, l_3, is attached to l_1, so as to move upon the axis m, (which point is flush with the right edge of l_1,) and a movable link, $o\,p$, is fastened to the plane-table and to the ruler l_3, so as to move freely on the axes o and p, the points A, m, o, and p being so placed as to form a parallelogram, the side A p of which lies in A b, thus keeping the ruler l_3 always parallel to the base A B. On the extension of this third ruler, beyond o, is marked a scale, the zero of which, n, is distant from m the length of A b; whence, also, the points A, m, n, and b will always form a parallelogram.

The ruler l_2, moved by electricity, slides over the ruler l_3, making with it the angle $n\,s\,b$=A $b\,s$ or A $b\,c$; as the angle $s\,n\,b$=m A p or c A b, it follows that the triangle $n\,s\,b$ is similar to the triangle A b c, and consequently also to the triangle A B C. Now

let x designate the number of parts read off from the scale $o\ n$, where the left edge of the ruler l_2 cuts it; the distance A C will be equal to (A B $\times n\ b$)$\div x$, $n\ b$ being a constant quantity, (say 8 inches,) and A B the distance between the two telescopes F_1 and F_2, in the multiple of the same unit of measure in which A C is to be ascertained. As, for a certain distance A B, the distance $m\ s$ will be the same for any direction of l_1, it is evident that the distance A C might be marked directly on l_3; but the apparatus could then, however, be used only for *one* base, (that for which the scale on l_3 has been constructed,) and the distances would then be proportional to the new base and not position.

The *direction* of the base will best be selected so that the space before it, in which positions are expected to be ascertained, shall be about divided in halves by a line drawn perpendicular to its centre; and the length should be measured in that unit of scale in which the apparatus is intended to indicate distances. (For illustrations and description of the electric apparatus, see pamphlet translated from the German for Bureau of Ordnance, Navy Dept., 1871.)

Electric Telemeter for Torpedoes.—The object of this apparatus is to determine the moment when a hostile vessel passes over the position of a submerged torpedo, and also, simultaneously, to explode the latter.

Two observers stationed at a distance from each other are necessary; but the distance need not be measured. Supposing that a series of torpedoes is submerged in a straight line, one of the stations is on the prolongation of this line, or near it if a reflector is used; and the business of the observer is to watch the passage of the enemy's vessels across it. The other station commands a cross view of the same line; and at this station the exact directions of the several submerged torpedoes are known. The telescope is of the altitude and azimuth construction, and an insulated metallic arm, which turns with the azimuth circle, touches successively a series of insulated conductors, which communicate severally with the torpedo toward which the telescope is at the moment directed. This contact closes a circuit which passes through both stations, and is broken at both, except when closed from time to time at the second in the movement of the telescope just described, and intentionally at the first by the observer himself.

It is the business of the first observer to touch the electric key whenever a vessel crosses the line. The second observer having his telescope directed at the same vessel, will necessarily, though unconsciously, close the circuit, if the vessel happens to pass over a torpedo. The touching of the key at the first station thus completes the circuit throughout, and the torpedo is exploded. But if the vessel crosses the line at a safe distance from any of the torpedoes, there will be no contact at the second station and the touching of the key will be without effect.

The introduction of additional observing stations is frequently of great importance to the security of the torpedo defense. By such a system, the ignition of the torpedoes is not left entirely dependent upon the concurrent observations of any one station. In the event of that station either falling into the enemy's hands or othewise being abandoned, the bearings of the torpedoes can then be determined, and the circuits closed with equal precision from another station. All land wires should be buried to prevent injury or discovery by the enemy. It is obvious that this method cannot be resorted to in foggy weather, nor in a dark night unless lights are used.

Danish method.—At each of the detached works forming the defenses of a harbor, is stationed an observer with a telegraphic apparatus and an instrument for measuring horizontal angles. The works are connected with each other and with a central station, from which all the operations are directed, by a submarine cable. Accurate charts and other facilities are provided for locating an object as soon as its bearings are determined.

When an object is discovered by either of the observers, the fact is reported by telegraph to the central station; and the officer at the latter designates two or more stations to prepare for an observation. When these report themselves ready, the word is given from the central station, and the results of the simultaneous observations are immediately reported back to it, and to each other. This operation is repeated at regular intervals; the object being located each time upon the chart and the direction and rate of its motion thus determined. If either of the works opens fire, the others not in the line of fire report the effect, as they can better observe the range of the guns. A plan similar to this could be used in conjunction with a system of torpedoes and artillery, employed in the defense of sea-ports.

King's Method.—Major W. R. King, in his "Notes on Torpedoes," suggests the following method of measuring distances of objects in motion: first, measure the angle subtended by the object as it passes a buoy or other point, at some distance previously determined; then use this angle and distance as units of measure in determining other distances for the same object. Thus, supposing the mast of a ship to subtend an angle of 10′ while passing a light-house 6,000 yards from the observer, and that on a second measurement, this angle is found to have increased to 20′, 30′, or 40′, the corresponding distances will be 3,000, 2,000, and 1,500 yards, respectively. By using a delicate micrometer in measuring the angles, this method would give very accurate results.

Camera.—The camera can be used for measuring distances if the actual dimensions of the object be known. Thus, if the distant object to be photographed be fifty yards long, and the image depicted on the focussing glass measures one inch in length, it is easy

to calculate the exact distance between the object and camera, knowing as we do the focal length of our instrument; if the latter be twenty five inches, it is clear that the object depicted in the camera is precisely 1,250 yards distant. In making these calculations, the image must always be sharply focussed, and accurately measured by means of a glass rule, upon which a finely divided scale is marked.

Camera Obscura.—Distances can be estimated by this apparatus. A graduated scale and vernier are used for measuring the distances on the image formed in the instrument. The apparatus must be placed at a considerable height above the distance to be measured, a different scale being required for each altitude. Recent experiments have demonstrated that this apparatus can be used in connection with a system of torpedoes, it being so placed that the image of a ship will be reflected on the mirror at the camera. When the image falls over a torpedo marked on the chart the electric current is applied and the torpedo fired. The torpedoes are numbered; each having a corresponding mark in the chamber.

Trigonometrical Problems may be divided into four general classes; 1. To ascertain the distance of an inaccessible object; 2. To ascertain the distance between two inaccessible objects; 3. To find the distance between two inaccessible objects, there being no station from which both can be seen; 4. To find the position of an object by means of two angles taken from it to three other objects, whose relative positions are known. As solutions of these problems are to be found in almost every work on surveying, it is not deemed necessary to give them here.

Distances computed by the velocity of Sound.—It is easy from the known velocity of sound, to compute the distance between two places which may be seen, the one from the other; and for this purpose let a gun be fired at one place, and the interval of time between seeing the flash and hearing the report at the other be carefully noted. This interval, expressed in seconds, multiplied by $1089{,}^{f}42\ \sqrt{1+(t-32^{\circ})\ 0{,}00208}$, the velocity of sound in air, will give the distance expressed in English feet. The value of t will be given by the Fahr. thermometer. The accuracy of this determination will of course be affected by the wind, should it be blowing at the time, but it will be sensibly independent of the state of the atmosphere or nature of the ground, etc. (*Bartlett's "Elements of Acoustics."*)

SUPPLEMENT.

BALLOON RECONNOISSANCES.*

If a reconnoitring officer could find a high structure on every mile of his route, it would much facilitate his operations. By one sight from such an elevation, he would be able to trace the courses of rivers and roads, running beneath him; and he would be able to lay them down in some sort of way without traversing them; he would, furthermore, be able to recognize the correctness of a map, should one be in his possession. Within his range of vision, the officer would be able to have certainly a much better idea than he could have from the ground, of the disposition of an enemy's forces; or, if it so happened, to establish the fact of the ground being unoccupied.

As the highest tree is but a few feet above its neighbors, while monuments, church spires, houses, etc., are seldom met with, the balloon is proposed to supply the above desideratum. It is intended by this means to have an apparatus permanently with an army, but with this difference, that in place of being established only every mile, it can be set up at will; and instead of being but 200 or 300 feet high it can be 1,000 feet or more.

Reconnoitring from a balloon is not a pleasant occupation, in fact a partial ascent is as unpleasant as the free ascent is delightful, the least wind causes the balloon to oscillate, and the motion both in ascending and descending, given to the car by the unequal action of the ropes is disagreeable; the danger, too, is much more in a partial than in a free ascent, and much caution is necessary. The mechanical condition of a balloon acted on by the wind, and kept to the ground by ropes, will be readily seen, and provided the current of air be constant, the difficulty would be easily overcome. The ropes having taken a proportionate angle, the balloon would remain steady, but the fickleness of the wind makes this impossible, and on the pressure being removed, the balloon would rise rapidly, to be as quickly thrown down again when the next gust came; in addition to which, the unequal action of the air on the silk would cause the balloon to struggle in such wise, as to make the car a very unpleasant place to be in. In these matters there is a wide difference between theory and practice; theory says the ropes will not break, and, if they do not, it is no more difficult to sit in the rocking car of a balloon than in a boat bobbing on the waves; but practice says, there is considerable difference.

To be applicable to military reconnoissances, a balloon should possess the following qualifications:—1st. It should be readily available after the order for an ascent has been given, and it should be capable of being used in any place. 2nd. It should be capable

* This should have appeared in Part I, as a 4th kind of Military Reconnoissances. [F. A. H.]

of being used in any wind less than 15 miles an hour. 3rd. The height capable of attainment must be 1,000 feet. 4th. The balloon must be able to take up two people at least, with ballast and the necessary observing apparatus. 5th. The balloon must be so made that it will retain its gas for a reasonable time.

During the late (American) war, balloons were made of the best silk, very strongly sewed, and were inflated with hydrogen produced from two generators, mounted on wheels, each being drawn by four horses. The gas was generated by the action of sulphuric acid and water on iron, and was passed through two lime purifiers before being delivered cool into the neck of the balloon. The balloons kept their gas for a fortnight, that is, having been filled, they still retained, after that time, sufficient ascensional power to be of use. In still weather they are allowed to rise 20 or 30 feet, so as to clear obstacles, and the men holding the guy lines marched along with the advanced guard; if the wind was at all high it was necessary to discharge the gas. The ropes, three in number, were made of silk; one was thicker than the other two, the intention being that it should take the main strain, the others acting simply as guys.

The method of manipulation was as follows: the main rope was passed through a snatch-block firmly attached to the ground, and each of the three having been manned by some ten men, the balloon was allowed to rise. Communication was maintained by shouting, when the altitude was small, and at 1,000 feet, messages were written on paper, and dropped with a stone to the ground. Communication by signalling was also established. Evening and morning were found to be the times generally best suited for observation, as the air was clearer and the shadows were larger. [*From a lecture by Capt. Frederick F. E. Beaumont, R. E., before the "United Service Institution."*]

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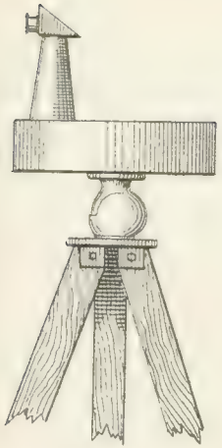


Fig. 1.



Fig. 2.

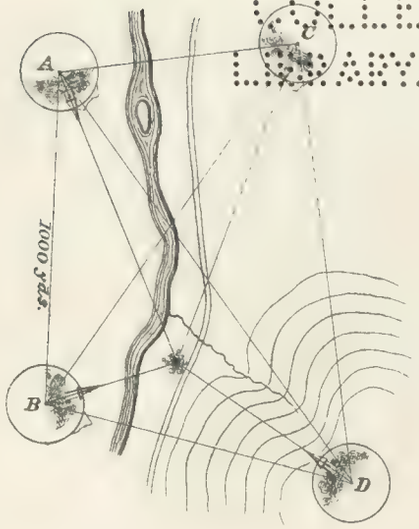


Fig. 3.

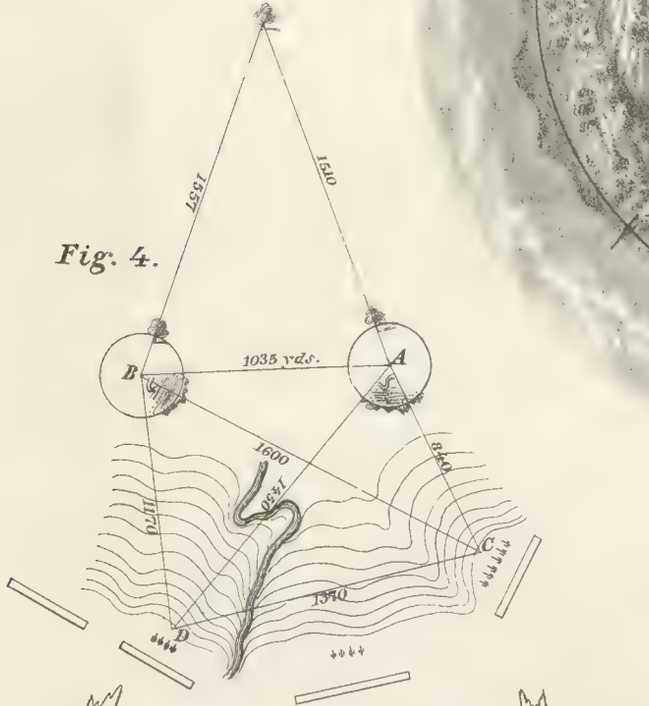


Fig. 4.

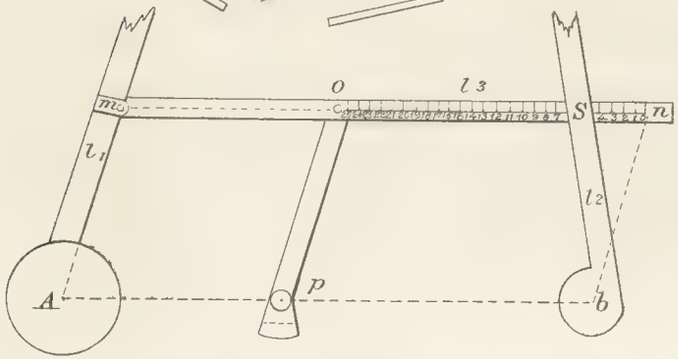


Fig. 7.

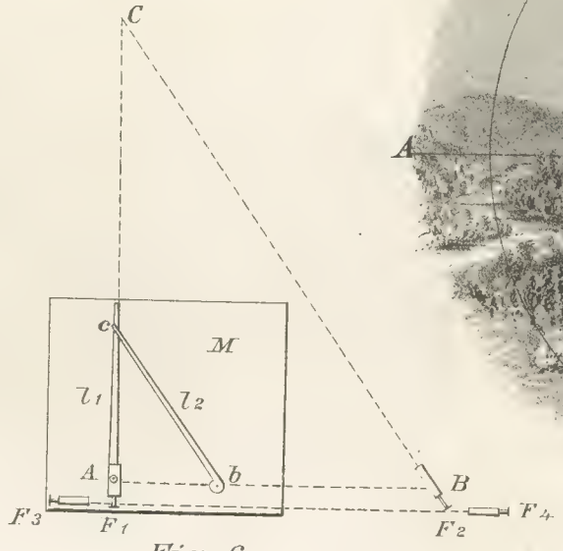


Fig. 6.

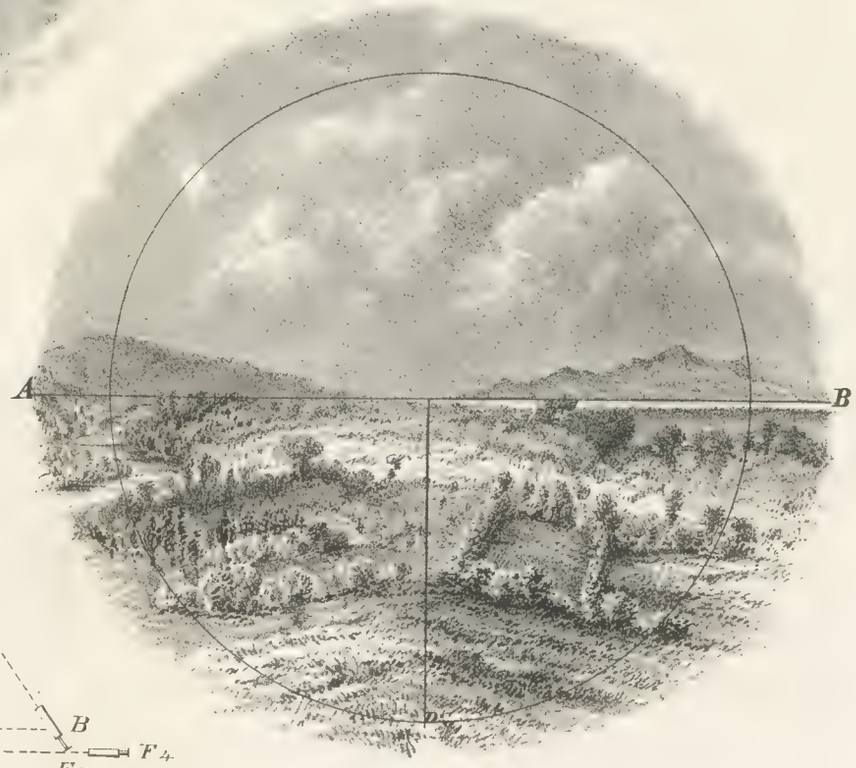


Fig. 5.

VENTILATION

OF

MILITARY MAGAZINES.

READ BEFORE THE ESSAYONS CLUB OF THE CORPS OF ENGINEERS,

APRIL 29, 1872;

BY

CAPTAIN WILLIAM J. TWINING,
CORPS OF ENGINEERS.

NO. XXII. PRINTED PAPERS.

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VENTILATION OF MILITARY MAGAZINES.

A paper read before the "ESSAYONS CLUB" of the Corps of Engineers, on April 29, 1872, by Capt. William J. Twining, Corps of Engineers.

There are two general classes of military magazines for the storage of gunpowder and ammunition: 1st. Those designed for permanent storage. 2d. Those designed for the service of batteries either in permanent or field works.

In either class the conditions of construction are safety, convenience of service and ventilation. The relative importance of these conditions depends on the position of the magazine and the service required of it, though whatever may be the circumstances, neither condition can be neglected without a serious sacrifice of efficiency. In storage magazines the condition of safety is very readily fulfilled. Therefore convenience of service and ventilation become of primary importance. The storehouses and magazines of arsenals belong to this class. Their positions can be selected remote from external sources of danger, while they also admit of much greater freedom of design and construction, and a far more generous allotment of space than is usually admissible in service magazines. Unembarrassed by questions of location and defense, the problems of convenience and ventilation are much simplified and appear to have reached a satisfactory solution in our more recent constructions.

For service magazines, under which general head may be classed all magazines of whatever kind used in fortified positions of small extent, safety is the primary consideration. Being in localities exposed to hostile attack, the work must be of such a kind as to defy penetration by direct fire, and to bear without injury the concussion of falling projectiles. Hence the necessity for massive walls and arched coverings, protected where exposed by earthern masks of great thickness and power of resistance. To avoid the possibility of penetration by fragments of bursting shells, the approaches to the inner chamber must be winding and intricate, and reduced to the smallest dimensions compatible with the due service of the magazine. Thus the consideration of service is par-

tially sacrificed to that of safety. In like manner the difficulties in the way of thorough ventilation are greatly increased, as the vast thickness of the walls and incumbent earth maintains within the magazine a temperature so low that air admitted for the purpose of ventilation is often reduced to a temperature of saturation, and instead of acting as a dryer, it actually introduces and deposits moisture; thus defeating its own purpose. Here also the difficulties common to the construction and service of all magazines are complicated by questions of space and drainage, and we may assume that any method of ventilation applicable to this case, can also be readily applied where no antagonistic conditions exist. I will therefore proceed to consider the general theory of ventilation as applied in civil construction and the modifications of that theory which are necessary to make it applicable to the service magazines of fortifications.

The general theory of ventilation as applied to the ordinary purposes of civil life, treats of the supply of pure atmospheric air to dwellings or other apartments inhabited for a greater or less extent of time, and usually includes warming as an essential condition. The problem in this case is to preserve a given standard temperature, to make good the loss of oxygen consumed by respiration or for purposes of artificial light, and to expel that portion of the atmosphere which may have become loaded with impurities injurious to animal life. Atmospheric air consists mainly of oxygen and nitrogen in a state of mechanical mixture, but always carries in suspension a greater or less proportion of aqueous vapor. Of this mixture the oxygen is the life supporting agent, which being removed there remains an atmosphere fatal to health and life, not from any inherent noxious or poisonous qualities, but simply from the fact that it is useless for purposes of respiration. When apartments are inhabited, or lighted by artificial means, there is a rapid consumption of oxygen, and a corresponding decrease in the life supporting quality of the air. To remedy this constant atmospheric depletion, there must be a continual introduction of external air, corresponding in amount to the quantity of oxygen consumed. The moisture carried in suspension may be disregarded. In certain cases it is of actual practical value in ventilation, from its power of absorbing ammonia and other hurtful gases. When the amount of vapor is so great that the air is in a state of saturation, the difficulty is usually remedied by artificial warming, which by increasing the capacity of air for vapor, dries the walls of the apartment, though the actual amount of moisture remains the same. It has followed from the system of ventilation of dwellings which require the constant introduction of oxygen to supply a definite waste, that a current of air has come to be considered the necessary condition of ventilation in all cases. This idea has, until quite recently, been followed out in the construction of military magazines for the storage of gunpowder, though a very casual consideration will show that

the circumstances are entirely different, and that their requirements must be met in a different manner.

The principal cause of the deterioration of gunpowder and fixed ammunition stored in magazines is the absorption of moisture, and it may be assumed that in arranging the ventilation of such places of storage we have to deal primarily with the vapor, and not with the life supporting principles of atmospheric air. Let us therefore examine the relations of co-existence of vapor and air, and the conditions which determine the deposition of the former in the form of moisture.

Water in a vacuum at once takes the form of vapor. The amount of this vapor will be determined by its own elastic force, and will not be affected by the presence of pure, dry air. To quote the language of Prof. Henry, "in free air the vapor exists as an independent atmosphere, being the same in weight and in tension as it would be in a vacuum of the same extent and of the same temperature." The process of diffusion of vapor in a vacuum is almost instantaneous, so that having given water, with a vacuum of given extent and temperature, evaporation will reach its maximum state in an inappreciable space of time. That is, the vapor formed will have reached a tension which will prevent further evaporation. This, however, does not hold true in free air. In this case the particles of atmosphere, though in a state of remote equilibrium, appear to offer a mechanical resistance to the free and rapid diffusion of vapor. Hence when air is in a state of absolute rest, the process of transmission is, for the time being, practically suspended.

The amount of moisture that can be contained in a given extent of atmosphere, depends upon the temperature, and its capacity of condensation is purely relative. Its measure is the rate at which evaporation will take place. Thus, when a wet and dry bulb thermometer are exposed together, if the two readings are the same, no evaporation is taking place; since such an evaporation would produce a depression of temperature, which would in turn be indicated by the wet bulb. That is, the limit of absorption has already been reached, and the air is said to be saturated. If now the temperature be reduced, there will be an immediate deposition of moisture. If on the contrary, the temperature be raised, evaporation will at once begin, showing that this elevation of temperature has given an increased capacity for vapor. Air in this state of complete saturation is said to be at the dew point. Owing to the resistance offered by the air to the transmission of aqueous vapor, this state of complete saturation is never reached except through the means of a reduction of temperature, whereby the actual carrying capacity is diminished. If reduced below the dew point condensation will take place equal in amount to the difference between the capacity of air for moisture at the two

temperatures. For purposes of comparison, the amount of vapor contained in air at full saturation is taken as a standard for each temperature, and the relation of the amount actually found to exist, to this standard, is the relative humidity. The actual amount of water in suspension in free air at saturation, for each degree of temperature, has been accurately determined, and will be found in a table attached to a subsequent part of this paper.

To make a practical application of the theory of vapor, as above stated, to the ventilation of service magazines, it is necessary to consider the circumstances of temperature as they occur in practice. The mean temperature of every magazine chamber will be the mean of the external temperatures, but the variation will be determined by the thickness of its masonry and earthern coverings. This limiting effect will rarely be less than that due to a mass of earth twelve feet in thickness.

The following extract is taken from Appendix III., Report on the Fabrication of Iron for Defensive purposes, Professional Papers of the Corps of Engineers.

"The transmission of the temperature of the air downwards through the earth's crust is retarded by the degree of non-conductibility of the strata through which the wave of heat or cold has to pass, and is neutralized by the mean temperature of the mass, which acts as a compensating reservoir of constant temperature, opposing all changes either toward excess or diminution. As the depth below the surface increases, the range of temperature is diminished and the time of recurrence of the maximum and minimum temperature retarded. At one inch below the surface the diurnal variations of temperature are reduced one-half; at three feet they do not exceed half a degree. The annual variation of temperature at Greenwich is indicated in the following table deduced from observations there."

Table showing annual variations of mean monthly temperature at different depths below the surface.

Depth below surface.	Above surface.	1 inch.	3.2 ft.	6.4 ft.	12.8 ft.	25.6 ft.
Annual range of temperature.	31°	29°	23°	16°	9°	3°
Time and amount of maximum temperature.	July. 67°	July. 66°	Aug. 62°	Aug. 59°	Sept. 55°	Dec. 52°
Time and amount of minimum temperature.	January. 36°	Jan. 37°	Jan. 39°	Feb. 43°	March. 46°	May. 49°
Mean annual temperature.	50°	51°	50°	50°	50°	50°

The average of the dew point was in this case from 2° to 10° below the temperature of the air.

This table shows an annual variation of only 9° at a depth of 12'.8, while the

variations of the mean monthly temperatures at the surface were 31°. It illustrates sufficiently the limiting effect of earthern coverings on the thermal variations within a magazine chamber. It also shows the retardation of the maximum and minimum states of the thermometer; for while the maximum temperature of the external air occurs in July, the maximum at a depth of 12.8 feet is not reached until September. In the case just cited, it was found that the mean temperature at the depth of 12 feet was lower than the dew point of the external air from the middle of April until the end of August. It was therefore agreed that a magazine having a corresponding thickness of earthen covering should be kept hermetically closed during this time; since if the outer air were freely admitted, there would remain in the chamber a deposit of moisture corresponding to the number of degrees of mean reduction below the mean of the dew point. This as a general theory is true, but in practice we have to deal with the question of ventilation each day, and not with a series of monthly means. We cannot assume that the necessities of war or of practice will allow our magazines to be kept constantly closed during certain months. On the contrary, it is reasonable to suppose that a magazine must be occasionally opened and that thereby moisture will be introduced. The walls will also absorb water from the surrounding earth, and transmit it by capillary attraction to the inner side. This will be especially true of brick walls, though the effect is partially counteracted by an inner lining. This capillary action is readily illustrated by immersing one end of a dry brick in water; moisture is absorbed by the portion below the water line, and is then rapidly carried upward by capillarity until it permeates the whole brick. This action is constantly going on in massive walls, especially where there is not a free evaporation from the outer surface. The dampness thus transmitted to the inner face remains until absorbed by a current of dry air. It follows then, that if even during a single day, the dew point of the external air is lower than the temperature of the magazine, the air should be admitted. At other times it should be carefully excluded.

For the purpose of illustration the following record of observations at Willet's Point, N. Y. H., during eight days in the latter part of July 1871, is appended:

Date.	Hour.	Air Therm.	Dew Point.	Date.	Hour.	Air Therm.	Dew Point.	Date.	Hour.	Air Therm.	Dew Point.
1871.		°	°	1871.		°	°	1871.		°	°
July 17	9 A.M.	72.7	66.9	July20	3 A.M.	65.5	61.5	July22	9 P.M.	64.0	48.7
	12 M.	75.2	60.8		6 "	63.6	60.0		12 M.	61.0	49.4
	3 P.M.	77.0	58.5		9 "	64.9	58.5	" 23	3 A.M.	58.0	47.8
	6 "	74.6	53.5		12 M.	70.5	54.7		6 "	57.2	48.6
	9 "	73.7	53.3		3 P.M.	72.3	56.9		9 "	65.0	50.7
	12 M.	64.8	54.0		6 "	77.5	60.3		12 M.	72.0	54.5
" 18	3 A.M.	62.0	54.0		9 "	68.5	58.0		3 P.M.	78.2	54.7
	6 "	60.0	52.8		12 M.	64.4	57.0		6 "	81.0	56.0
	9 "	67.4	54.2	" 21	3 A.M.	62.5	54.8		9 "	67.0	56.4
	12 M.	76.2	56.7		6 "	61.8	57.5		12 M.	63.7	54.2
	3 P.M.	80.0	57.2		9 "	67.4	58.9	" 24	3 A.M.	60.5	52.5
	6 "	77.2	56.5		12 M.	72.2	58.5		6 "	60.8	55.9
	9 "	67.5	58.7		3 P.M.	76.0	58.5		9 "	66.4	58.8
	12 M.	68.7	62.7		6 "	76.0	58.9		12 M.	73.0	59.2
" 19	3 A.M.	66.0	60.5		9 "	65.5	58.3		3 P.M.	76.0	58.6
	6 "	67.8	63.7		12 M.	63.5	56.8		6 "	74.0	61.5
	9 "	67.2	65.0	" 22	3 A.M.	63.3	57.3		9 "	73.5	59.8
	12 M.	67.7	64.7		6 "	61.1	57.1		12 M.	67.0	60.3
	3 P.M.	68.9	66.2		9 "	66.2	55.5	" 25	3 A.M.	65.5	60.4
	6 "	68.1	64.7		12 M.	70.0	53.7		6 "	64.5	59.6
	9 "	67.8	63.9		3 P.M.	76.5	51.1				
	12 M.	66.8	64.2		6 "	74.0	50.6				

Assuming the mean annual temperature to be 51°.5, (the mean at Fort Hamilton, N. Y. H.) and allowing only 3° above the mean, we have as the probable temperature of a magazine 54°.5; which is above the observed dew point of the external air for an interval of time extending from noon on the 22nd until noon on the 23rd. It is probable that in most localities a far more favorable condition will be found to exist than is shown here.

During the winter months the question of ventilation is much simplified, as the temperature of the atmosphere is usually below that of the magazine, and the external air may then be freely admitted. But this will depend on the humidity of the climate and its character as regards rapid changes of temperature.

The only safe rule which can be applied for all seasons and all localities, is the one

already stated; viz: when the temperature of the dew point of the external air is below the temperature of the magazine the air may be admitted; at all other times it should be carefully excluded.

The application of this rule involves the frequent determination of the dew point. This may be found directly from the Hygrometer, but as the accurate use of this instrument requires considerable skill and practice the Psychrometer will be found simpler and more convenient for general use. To find the dew point by this method, multiply the difference of readings of the wet and dry bulb thermometers by the proper factor taken from the following table, and subtract the product from the reading of the dry bulb; the remainder is the temperature of the dew point.

TABLE OF FACTORS.

Dry bulb Therm.	Glaisher's Factors.	Dry bulb Therm.	Glaisher's Factors.	Dry bulb Therm.	Glaisher's Factors.	Dry bulb Therm.	Glaisher's Factors.	Dry bulb Therm.	Glaisher's Factors.
°		°		°		°		°	
26	6.08	41	2.26	56	1.44	71	1.76	86	1.65
27	5.61	42	2.23	57	1.92	72	1.75	87	1.64
28	5.12	43	2.20	58	1.90	73	1.74	88	1.64
29	4.63	44	2.18	59	1.89	74	1.73	89	1.63
30	4.15	45	2.16	60	1.88	75	1.72	90	1.63
31	3.70	46	2.14	61	1.87	76	1.71	91	1.62
32	3.32	47	2.12	62	1.86	77	1.70	92	1.62
33	3.01	48	2.10	63	1.85	78	1.69	93	1.61
34	2.77	49	2.08	64	1.83	79	1.69	94	1.60
35	2.60	50	2.06	65	1.82	80	1.68	95	1.60
36	2.50	51	2.04	66	1.81	81	1.68	96	1.59
37	2.42	52	2.02	67	1.80	82	1.67	97	1.59
38	2.36	53	2.00	68	1.79	83	1.67	98	1.58
39	2.32	54	1.98	69	1.78	84	1.66	99	1.58
40	2.29	55	1.96	70	1.77	85	1.65	100	1.57

It will be advisable to allow a margin of 2° for error in the determination of the dew point.

Having thus considered at length the general theory of ventilation of magazines by natural currents of air under certain selected conditions of temperature and humidity, the method of inducting these ventilating air currents remains to be discussed.

All natural ventilation depends on the fact that air expands and therefore increases its specific gravity with every increase of temperature. Hence, having given a volume

of air undisturbed by external forces, it will arrange itself in horizontal strata, according to temperatures, like fluids of different densities. Every motion of such an arrangement induced by a change in the relative heat of the different strata, will take place in a vertical direction. Thus if the temperature of the upper air is reduced, its specific gravity is increased; it will therefore fall by its own weight, and force upward the warmer and lighter strata. For example, suppose a column of air to be enclosed in a tube of such thickness as to retain a temperature different from that of the surrounding atmosphere. Both ends of the tube being opened, if the temperature of the column be lower than that of the free air, it will gradually flow out at the bottom, by the action of gravity, its place being supplied from above; this inflowing air is slowly cooled and the action repeats itself as before. On the contrary, making the external air the coldest, it will force upward the lighter column within the tube, thus reversing the previous action. In this we have an illustration of what takes place in a magazine with a proper arrangement of ventilation. The ventilators near the top, in connection with the chamber and doorway, form a continuous tube in which the air takes the temperature of the surrounding masonry, and of which the ends may be opened or closed at will. When opened, the direction and velocity of the inflowing current will be determined by the relative temperatures within and without the magazine.

In this connection, the use and arrangement of an interior lining naturally suggests itself. It may serve two purposes. In the first place it cuts off from the chamber the moisture on the walls, due to transmission by capillarity from the surrounding earth, by interposing a column of air at rest. As air in a state of rest is a bad conductor, both of heat and moisture, the effect is most complete when the diaphragm is air tight and is constructed of material with a low power of conductibility. In a second point of view, the air space between the lining and the wall may be used as a channel for passing warm currents of external air, for the purpose of raising the temperature of the magazine. In this case there will be a great condensation on the wall, and the wood work will rapidly decay. The amount of heat gained will be the amount due to the reduction of the air temperature, plus the latent heat of the vapor, given up in the process of condensation.

The efficiency of such an arrangement is at best rather doubtful except as a temporary expedient. No moisture is removed from the magazine. It is simply taken up by the air and remains as vapor, to be immediately deposited so soon as the temperature is again reduced. I would therefore make the ventilation of this air space entirely separate from that of the interior chamber, but would apply the same rule in regard to the

admission of external air that has already been given for the ventilation of the magazine itself.

It may be that in some damp localities, and for large and important magazines, no system of natural ventilation will suffice. In such a case either the powder should be stored in air-tight cases, or some system of artificial ventilation should be adopted. A current of warm air driven by machinery would, on first thought, appear to answer the purpose. But this air on coming in contact with the cold walls would give up its vapor just as certainly as though it were at its ordinary temperature. By reducing its temperature by artificial means, and driving it cold into the magazine, a much better result would be obtained; since by this means, the excess of moisture would have been deposited before the air was introduced, and its dew point would be below the temperature of the walls. The expense and constant care required would be a serious objection to such a method.

A much better remedy for the dampness will be found in the use of artificial dryers. The actual quantity of water to be absorbed is not large, as will be seen by reference to the following table:

WEIGHT OF VAPOR IN GRAINS TROY, CONTAINED IN A CUBIC FOOT OF SATURATED AIR.

Deg. Fah.	Degrees Fahrenheit.									
	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°
°										
0	0.545	0.569	0.595	0.621	0.649	0.678	0.708	0.739	0.772	0.806
10	0.841	0.878	0.916	0.957	0.999	1.043	1.090	1.138	1.190	1.243
20	1.298	1.355	1.415	1.476	1.540	1.606	1.674	1.745	1.817	1.892
30	1.969	2.046	2.126	2.208	2.292	2.379	2.467	2.563	2.659	2.759
40	2.862	2.967	3.076	3.189	3.306	3.426	3.550	3.679	3.811	3.948
50	4.089	4.234	4.383	4.537	4.696	4.860	5.028	5.202	5.381	5.562
60	5.756	5.952	6.154	6.361	6.575	6.795	7.021	7.253	7.493	7.739
70	7.992	8.252	8.521	8.797	9.081	9.372	9.670	9.977	10.292	10.616
80	10.849	11.291	11.643	12.005	12.376	12.756	13.146	13.546	13.957	14.378
90	14.810	15.254	15.709	16.176	16.654	17.145	17.648	18.164	18.693	19.235
100	19.790	20.357	20.938	21.535	22.145	22.771	23.411	24.069	24.742	25.429

For every 1,000 cubic feet of air space in a magazine the entire weight of the vapor held in suspension at full saturation, at a temperature of 60°, could only be one lb. Troy. To reduce the dew point to 40° it would be necessary to remove by absorption six ounces of water. This could be easily done by the use of unslaked lime, which when pure and perfectly anhydrous will take up one-third of its own weight of water without difficulty. As the use of unslaked lime in a magazine would be attended with a certain

amount of danger, owing to the heat evolved in the process of slaking, it would be well, where the circumstances would warrant the expense, to attach a small drying chamber to the main magazine, divided from it by a copper wire screen extending from floor to ceiling. The heat developed in the process of slaking would probably be sufficient to establish a slow circulation of air between the two chambers.

THEORY

OF

BAROMETRIC OSCILLATION.

READ BEFORE THE ESSAYONS CLUB OF THE CORPS OF ENGINEERS,

MAY 22, 1872;

BY

LIEUT. WILLIAM L. MARSHALL,
CORPS OF ENGINEERS.

NO. XXIII. PRINTED PAPERS.

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THE HORARY OSCILLATION OF THE BAROMETER.

A paper read before the "ESSAYONS CLUB" of the Corps of Engineers, on May 22, 1872, by Lieut. William L. Marshall, Corps of Engineers.

The height of the barometric column reduced to 32° Fahrenheit is continually changing.

This change is the resultant of two separate, independent motions, which are more or less rapid, but gradual.

The first of these components, called the abnormal oscillation, is that by which the mean daily barometric heights vary from day to day. As its name implies, it is of irregular character, subject, so far as known, to no law of variation or recurrence, but so slow and gradual that it usually takes several days to pass from a "low" to a "high" barometer; or from the base to the summit of one of these wave-like oscillations.

The second, or horary oscillation, is that by which the height of the barometric column varies from hour to hour in a regular and even manner, attaining during the day to two maxima and two minima heights; the maxima occurring between the hours 8 and 10 A. M. and 10 and 12 P. M., and the minima between the hours 2.30 and 5.30 P. M and 2 and 4 A. M. The maxima are not eqnal to each other, nor are the minima equal, but the morning maximum and the afternoon minimum are generally more decided than the corresponding points at night.

The horary oscillation diminishes from the equator where it is greatest, to the poles where it is least. It diminishes also from the sea level to high altitudes, differing also at high altitudes in its critical hours. This last, however, is not well settled, as comparatively few horary observations have been made at high altitudes.

In the United States the extreme range of this oscillation varies from about .040 to .120 of an inch, corresponding to an extreme variation of barometric pressure of from one-third of an ounce to one ounce avoirdupois, per square inch.

Although the general character of the horary oscillation remains constant, the

particular oscillations for different months, days, seasons and years, vary among each other, and they also differ when we go from place to place.

These are the general facts known in regard to this oscillation, and which are to be accounted for.

The horary thermal oscillation, or change in the amount of heat received from the sun from hour to hour, is the efficient cause of the horary oscillation of the barometer.

The air being a non-conductor of heat and very diathermanous, is not heated by direct rays from the sun, but only by contact with some warm body, or by heat evolved during the condensation of aqueous vapor.

The revolution of the earth upon its axis exposes each meridian in succession to the calorific action of the sun's rays, which, incident upon the earth's surface, heat it and the air in contact with it.

As the altitude of the sun increases, the earth receives more and more heat and the temperature rises, the *rate of increase* of temperature being a maximum, on an average, at about 10 A. M., and the actual amount of heat received in a given time a maximum when the sun is on the meridian. The temperature continues to rise after this epoch, however, until the radiation from the earth's surface is just equal to the amount of heat received from the sun, which occurs between 1 and 4 P. M., when the maximum temperature for the twenty four hours is attained. After this instant radiation cools the earth's surface and causes the temperature to fall, with a numerically increasing decrement, until near sunset, when the *rate of decrease* is a maximum; after which time the temperature still continues to fall, more and more slowly, until about 4 A. M., when the minimum temperature is reached.

Such is the horary thermal oscillation. This primary cause calls into action two secondary causes, each of which produces its effect upon the barometric height. These causes are:

1st. The varying weight, or elastic force of the aqueous vapor in the air. 2d. The expansion and contraction of the atmosphere.

We will take each of these causes, in order, and explain its effect in producing a horary barometric oscillation.

1st. AQUEOUS VAPOR.

According to Mr. Dalton's theory in regard to the constitution of gases, each gas is a vacuum to all other gases, that is: two or more gases may occupy the same space, each exactly as if the other or others did not exist. Vapor of water is a gas, or similar to a gas, and exists to a greater or less extent in all air. It is invisible, compressible, and elastic;

if compressed until its density reaches a certain point, at any given temperature, or if its temperature is reduced below a certain point, part is precipitated as dew. As long as the temperature is above the dew point, aqueous vapor acts in precisely the same way as the atmosphere, or any other gas, upon any change of temperature, and is subject to the same laws as regards contraction and expansion. At any given temperature the air can hold a certain amount of vapor, and no more, this amount increasing with the temperature.

As long as the temperature of the air is above the dew point, it acts like a sponge and takes up moisture from all surrounding bodies below the dew point, part of which is deposited as dew when the temperature is reduced. The weight therefore of the aqueous vapor in the atmosphere is continually changing, and must have its effect upon the horary oscillation of the barometer, in modifying the effects of the other causes of variation.

Regarding this cause alone, it must, by its weight or elastic force, increase the height of the barometer beyond what is due to the pressure of the dry air, and from its hourly varying amount and weight produce its own horary barometric oscillation, which co-exists and is superposed upon the motions produced by other causes. This horary oscillation if due to the weight of the aqueous vapor, alone, would have but one maximum and one minimum point; the maximum occurring when the maximum amount of vapor is present in the air, which takes place between 1 P. M. and sunset, and the minimum about the time of lowest temperature for the day, or, on an average, about 4 A. M.

To enable us to find approximately this component of the horary oscillation of the barometer, tables have been constructed which give the force of vapor for every degree of the Fahrenheit scale, within certain limits, from which tables, knowing the temperature of the dew point from observation, we may find the force of vapor expressed in inches of the barometric column.

2nd. EXPANSION AND CONTRACTION OF THE AIR.

1st. Change in weight of the column of air pressing upon the surface of the mercury in the barometer's cistern.

The air, like all other gases, expands with an increase of temperature, and contracts when the temperature is lowered. During the time then, that the earth is receiving more heat from the sun than it loses by radiation, or as long as the air is increasing in temperature, it expands, and the barometer should indicate less pressure.

1st. Because part of the air that filled the column of which the area of the base is the cross section of the barometer tube, and the altitude, the altitude of the atmosphere, has, by its expansion, been made to occupy a larger space, part of the air having

been pressed laterally out of this column.

2nd. From the flowing off at top of the air raised above the neighboring atmosphere.

3rd. From the diminution in the weight of the particles due to the increased distances of their centres of gravity from the centre of the earth.

Of these, probably the first produces the greatest effect, because the air near the earth's surface being the most heated, and the heaviest of the entire column, is expanded proportionately more, and suffers for the same volume, a greater loss of weight. The air at the outer limit of the atmosphere being very rare, the weight of that flowing off at the top is but little, and what is lost in a short time is scarcely measurable by the barometer.

The diminution of the intensity of the force of gravity acting upon the particles of the different strata, is also very small; the different centres of gravity of the several strata being raised only through a distance equal to the sum of the expansions in a vertical direction of the strata below them respectively, which is small, compared with the distance to the centre of the earth.

When the temperature decreases, the reverse takes place, and the pressure due to the *weight* of the air is increased. Hence, if the horary thermal oscillation affected the *weight* only of the column of air pressing up the mercury in the barometer tube, the horary barometric curve would show but one maximum and one minimum, the maximum occurring at the time of lowest temperature, and the minimum at the time of maximum temperature, or a minimum at about 2 P. M. and a maximum at about 4 A. M.

If there were any law of diminution of temperature with increased altitude, or if the temperatures of the different strata varied in accordance with any known law, we might, knowing the rate of expansion of the compound atmosphere, etc., approximate pretty nearly to the effect this expansion or contraction may have upon the weight of the entire pressing column; but as the air can be heated only by contact with a heated body, by convection or by the heat evolved during the condensation of aqueous vapor, it is probable that the horary thermal oscillation does not extend very high; that before the air which acquired its heat at the earth's surface has reached a certain height, most of its heat has been converted into work in expanding itself and overcoming the resistances to its upward motion, so that before the effect of the increase of temperature at the earth's surface during the morning and mid-day has extended to any considerable height, the air below is becoming cool from radiation. If such be the case, the horary change of temperature above a few thousand feet, where there is no solid body, as a mountain for instance, to heat the air by contact, is inappreciable, although the annual change, which is the re-

sultant of a long series of horary changes, may be easily seen, as in the change in the altitude of the snow line on mountains' sides, etc.

"From a long series of observations, it has been determined that the rate of decrease of temperature with increase of elevation, varies with the latitude, the season of the year, and with the hour of the day. It diminishes more rapidly in warm than in cold climates, and is more rapid in the warm than in the cold months. It is most rapid near the hottest part of the day and least rapid about sunrise, when the surface temperature is the least."

At night, when the radiation from the earth's surface is rapid, we may often find the temperature of the stratum of air near the ground several degrees lower than it is 10 or 12 feet higher, above which height we may have to ascend to quite a considerable altitude before we find a further increase of one degree, all of which but confirms the impression that the expansion and contraction of the air due to the *horary* variation in daily temperature, is confined to a comparatively thin stratum near the surface of the earth; the air above this stratum expanding and contracting only because it is made, by the expansion and contraction of the air below, to fill and vacate, the space enclosed between its mean upper surface and the surface of a concentric sphere, described with a greater or a shorter radius; from which it follows that the increase and diminution in the *weight* of a given column of air, due this cause, is less than if we should assume that the entire column of air expanded in accordance with the hourly change of temperature as exhibited by a thermometer at the earth's surface, and that the effects of this cause have been exaggerated, whatever may be the monthly or annual change in weight, due to a monthly or annual change in temperature.

From what has been said of the effects of the varying force of aqueous vapor, and of the increase and diminution of the weight of the air, due the hourly variation in temperature, it will be seen that they affect the height of the barometer in opposite directions, and should either neutralize each other's effects, or give a horary barometric oscillation of the same general character as that which would be produced by that one of these two causes which predominates.

But the horary oscillation of the barometer cannot be produced by any combination of these two elements as they actually exist. We must therefore seek some other cause, whose effect upon the barometric height so far exceeds the sum of the effects of the other causes, as to give *its own character* to the resultant horary oscillation.

This cause may be found in the resistance which the inertia of the superincumbent air opposes to the contraction and expansion of the strata near the surface of the earth.*

* Since this paper was written, it has been ascertained that this theory was first suggested by Prof. James P. Espy, in his 4th Meteorological Report.

To show what may, possibly, be the effects of this resistance upon the height of the barometric column, I shall assume that the air near the surface of the earth alone contracts and expands, and that the weight of the air above this pulsating stratum is a constant one, raised and lowered by the expansion and contraction of the stratum below.

It may be well to call attention to the fact that although the *weight* of the air, at the level of the sea, may exert a pressure equivalent to 15 lbs. per square inch, yet in discussing the motion of this vertical column, we cannot assume that the resistance which its inertia opposes to motion, is the same as that which the inertia of a body, weighing 15 lbs. at the sea level, would oppose; for the reason that the force of gravity diminishes rapidly with increased distance from the centre of the earth, and consequently, although the higher strata of the air may weigh little, yet they have more mass than their weight, as measured at the earth by the barometer, would indicate; and the resistance of their inertia which depends upon the mass and not upon the weight, is proportionally greater.

At about 4 A. M. the temperature is a minimum. There is neither contraction nor expansion of air near the earth's surface, due to change of temperature. The inertia of the superincumbent air is not called into action, and the barometer not thereby affected. The temperature begins to rise. The air expands and raises the column above it. Its inertia resists the expansive action of the lower air, which reacts with a pressure equal to this resistance upon the surface of the mercury in the cistern of the barometer, and causes the barometric column to rise. The altitude of the sun increases. The temperature rises more and more rapidly. The air expands with a force increasing in intensity, and develops a greater and greater resistance of inertia in the accelerated column; reacts upon the mercury in the cistern with an increasing pressure, and the barometer continues to rise as long as the increase of temperature is accelerated, attaining its greatest height when the acceleration of temperature is a maximum, or sometime between 8 and 11 A. M., depending upon the latitude of the place and declination of the sun.

After this instant the hourly acceleration or increment of temperature diminishes. The intensity of the motive force being diminished, the inertia of the upward moving column reacts with a less intensity upon the surface of the mercury in the cistern and the barometer being relieved from pressure, begins to fall. The air having an upward motion and being still compressed at the base of the column, moves on upward to regain its position of equilibrium, and as the accelerating force is constantly diminishing, the higher strata will probably have attained nearly their proper distances apart at the time of maximum temperature, when the accelerating force is zero, although still somewhat compressed. The column still continues its upward motion. The air at the base begins

to cool slowly and contract, and the barometric column at about the time of maximum temperature should fall rapidly. The moving column having been carried by its own momentum past the position of equilibrium, will soon begin to fall and oscillate until the friction, etc., between its particles will destroy its motion. The barometer will record these oscillations, and the barometric curve, after the time of maximum temperature, should show one or more undulations; but as the temperature is falling and the base of the column contracting, the general motion of the column of air will be downward, and as the temperature falls more and more rapidly, the superincumbent air, having been pressed upward during the increasing temperature, now, when it is diminishing, falls, following the contraction near the surface of the earth. As long as the temperature decreases with a numerically increasing decrement, the air near the surface contracts more and more rapidly; the inertia of the descending column of air acts upward in opposition to its downward, increasing rate of motion; the barometer is relieved from part of the pressure, and therefore continues to fall. This relief is a maximum when the rate of decrease of temperature is a maximum, which occurs generally about three hours after maximum temperature. After this instant, the decrement is numerically less and less. The downward motion of the column of air is checked, and the inertia of the upper strata acting downward, compresses the air in contact with the mercury in the cistern, and the barometer again begins to rise and continues to rise until the maximum compression takes place. This should occur about three or four hours after sunset, as the *rate* of decrease of temperature is nearly uniform after that time, and the downward motion of the column of air nearly uniformly retarded.

This checking of the downward motion of the column of air, has, on account of its compressibility and elasticity, the effect of compressing, first, the lowest stratum, then the strata above, stratum by stratum in succession, until the whole column is brought for an instant to rest. It is at this moment of maximum compression, that the maximum pressure is exerted, and the barometer consequently attains its second maximum. Immediately thereafter, the air, by its elastic force, reacts to regain its position of equilibrium, gradually relieving the barometer from pressure, and it again falls. Since the column of air will be carried upward by its living force, past its position of equilibrium, the barometer will fall below the normal height, due to the weight of the air alone, attaining its second maximum when the air has reached its highest point. The column will again descend and continue to oscillate until brought to rest by the friction, etc., between the moving particles of its different strata; but as each of these oscillations will be less than the first, the general motion of the barometric column will be a rising one, until the column of air is brought to rest, when the barometric column will resume its normal

height due to the weight of the air alone. If the night be short, as in summer, possibly before the first oscillation after the second minimum is completed, the air has begun to expand from increasing temperature and a recurrence of the same series of phenomena will begin.

If it be admitted that the air cannot rise until its specific gravity is lessened by expansion, and that it cannot expand without pressing equally in all directions, it *must* also be admitted that the inertia of the air above will be developed, and the consequences shown will follow as a matter of course.

This theory of the change in pressure due the inertia of the air above, without a change of weight, will account both for the greater oscillation at the Equator, and the diminished oscillation at high altitudes.

At the Equator the diminution of the weights of the particles of air due to their increased distances from the centre of the earth, and, also, of those particles which remain at rest with respect to the earth's surface, by the centrifugal force, requires a higher column of air to equilibrate the air pressing on other parts of the earth's surface, hence, for reasons already given, the mass of the air pressing upon any given area at the Equator, is greater than at higher latitudes; and the resistance which its inertia opposes to the expansive force of the air is consequently greater; or for the same acceleration and retardation there must be a greater effect produced upon the height of the barometric column. Add to this the fact that the intensity of solar action is much greater at the Equator than elsewhere, and the greater oscillation may be well accounted for.

Here the air is generally rising and flowing off toward the poles, at top, but this upward motion is retarded, if not stopped, at night, and it is the *relative* acceleration and retardation of the motion of the atmosphere, which causes the horary variation in the height of the barometer. The general upward motion of the air having, in a manner unnecessary to explain here, the effect only of lessening the mean height of the barometer at the Equator.

At the Equator, also, heat the great motive power, which has become latent in the evaporation of water, is given out in the condensation of aqueous vapor during the great rains of that region, and, by the contraction and expansion caused thereby, may also produce certain fluctuations in the barometric height, and affect the horary oscillation in a manner it is impossible, from any data we may have, to indicate.

At high altitudes the mass of the air above is less, and the hourly increment or decrement of temperature is less than at lower; for both of which reasons the horary oscillation, due to the inertia of the moving column, must be less.

In winter the diurnal range of temperature is less, as a rule, than in summer. The

acceleration and retardation of the moving column must consequently be less; and if the mass of the air pressing upon the mercury in the cistern of the barometer were the same as in summer, the horary oscillation, due to the resistance of inertia, would be less in proportion to the less diurnal thermal oscillation; but as the mean temperature of the air is less in winter than in summer, it is less expanded, and a greater mass of air presses upon an area equal to the cross-section of the barometer tube, and a proportionately less acceleration and retardation would be required to produce the same effect; therefore, although the horary oscillation may be less in winter than in summer, it will not be less in the proportion given.

In winter, when the sun is a shorter time above the horizon, the time of occurrence of the morning maximum should be later, and of the afternoon minimum earlier than at other seasons; hence, the day portion of the horary oscillation should be more abrupt in winter. In winter, also, there is less aqueous vapor in the air; this conservator of heat being less, the temperature will fall more rapidly than in summer; the air will acquire a more rapid downward motion; this motion will be checked more rapidly, and we would therefore, expect the first portion of the night oscillation to be more marked, and the second maximum to be attained sooner than in summer; but as there will be a much longer interval of time between the second maximum and the time of lowest temperature, during which the column of air will oscillate about its position of equilibrium, the night minimum will not be so decided as in summer, but the winter curve after the second maximum will be wavy, with several secondary maxima and minima points.

The horary oscillation varies from one season, or month, to another, both in its extent and the times of occurrence, of its culminating points, depending upon the relative lengths of the days and nights; the diurnal range of temperature, and the extent to which it may be modified by the other causes of variation already given.

When the sky is overcast similar effects are produced, though it would appear that the horary oscillation should be less than on a clear day. The cloud acts like a sheet of water at the earth's surface; absorbs heat from the sun's rays, and radiates it into space; heats the surrounding air by contact, and cools it by radiation; vapor of water is formed from it by evaporation, and condensed within it or around it by the reduction of temperature attending radiation. Although the cloud may prevent the usual horary thermal oscillation at the surface of the earth; this takes place at the cloud; the pulsation of the motive stratum of air occurs, and produces similar effects, which are transmitted to the cistern of the barometer by the elasticity of the intervening air.

SUMMARY.

From the above we see that, theoretically, the effects of this cause of variation in the pressure upon the earth's surface, are:

To produce a maximum height of barometer somewhere between 8 and 11 A. M., a minimum near sunset, a maximum before midnight and a minimum between midnight and the time of lowest temperature, depending upon the acceleration or retardation of the moving column of air, due to the rate of change in hourly temperature.

That the horary oscillation at the equator, other things being equal, should be greater than at higher latitudes, and at high altitudes less than at lower, and that it should also, be less on a cloudy than on a clear day.

The time of maxima and minima, as well as their magnitude, as determined by this last cause alone, must be modified by the sometimes conspiring, sometimes opposing motions produced by the other causes of variation, the general effects of which I have already given.

I will now resolve the resultant curve representing the horary oscillation of the barometer, into its components, and, if after eliminating the effects of the two causes first named, a curve remains, which in its general characteristics coincides with the curve which must be produced if inertia is called into action, then we may with some reason conclude that this is a possible solution to the problem, or that it at least merits further examination before it is totally rejected.

Of the three component motions of which we have assumed the horary oscillation of the barometer to be the resultant, that due to one of the causes named is given by the force of vapor, which, plotted, represents the component horary oscillation as affected by that cause alone.

I have obtained the ordinates of the curve representing the increase and diminution in the *weight* of the air due to its contraction and expansion in this way. I have assumed, for want of any other rule, that the air expands, or contracts, $\frac{1}{500}$ of its entire volume, for a change of temperature at the earth's surface of 1° Fahrenheit, and that the weight of the entire pressing column varies in the same proportion. Neither assumption is correct; but the resulting curve will be of the same general shape, and with its maxima and minima points at the same hours, as if we had assumed the true law of expansion or variation.

Take the mean height of the barometer for the twenty-four hours and divide it by 500: the quotient will be the change in weight of the pressing column expressed in

inches of barometric height, due to a change of 1° Fahrenheit in temperature. Subtract the temperature at each hour from the mean temperature for the day, and multiply the remainder by this quotient; the products will be the ordinates of the curve representing that component of the horary oscillation due to change in weight of the column of air pressing up the barometer tube.

The horary oscillation of the barometer is the resultant of all the component motions; of the three assumed we now have two and the horary curve itself; the third is easily found; thus, if

h=ordinate of the horary barometric curve,
v= " " vapor curve,
w= " " change in weight curve,
z= " " curve representing component motion produced by

all other causes of variation, we have,

$$h=v+w+z, \text{ or } z=h-(v+w).$$

In this manner I have constructed the curves shown on the plate attached to this paper; the mean horary curves from several days' hourly observations, reduced by Major Williamson's method, and published in orders from the Headquarters of the Battalion of Engineers, having been taken as examples. The reductions described are given in the annexed table.

The midsummer inertia curves so obtained are not perfectly smooth; the curves given in the plates are traced so as to give the general sweep of these curves; the points determined as above being represented on the drawing by dots.

Comparing the summer curves with each other and the winter curves in the same manner, it will be seen that the times of maxima and minima are nearly the same in each set, and agree as nearly as could be expected with their places as determined theoretically in the discussion of the effects of the resistance of inertia to the expansive force of the heated air, etc. If an exaggerated value had not been given to the change in weight-component oscillation, the curves would have more nearly approached the resultant horary curves.

These are the only sets of observations I have reduced by this approximating method. It can hardly be expected that the inertia curves will always, or even generally be found approaching so near their typical form as do these; because of the erroneous force of vapor we are likely to obtain from observation, however carefully made; and any error in this will enter with its full value into the inertia curve when constructed in the manner just explained. It would be better to find an expression for the varying temperature expressed in terms of the sun's hour angle; then knowing the rate of expansion of

air at any temperature, and supposing this expansion to be confined to a thin stratum near the earth's surface, we could determine very nearly the acceleration of the motion of the air above this stratum at any instant, and the resistance which its inertia opposes to this change of motion ; and construct the curve mathematically. To deduce such an expression would require more time than is at present at my disposal, and it is deferred until a more favorable opportunity may present itself.

MID-SUMMER HORARY CURVES.

Hour.	West Point, N. Y., July, 1871. (Means of 30 days observations.)							Willet's Point, N. Y., July, 1870. (Means of fifteen days observations.)						
	Temp.	Var'n. from Mean.	w	v	$(w+v)$	h	z	Temp.	Var'n. from Mean.	w	v	$(w+v)$	h	z
	°	°	″	″	″	″	″	°	°	″	″	″	″	″
7 A. M.	68.4	—2.2	—.015	+.012	—.003	—.019	—.016	73.4	—4.9	—.029	+.011	—.018	—.037	—.019
8 "	69.2	1.4	.008	.008	.000	.021	.021	75.4	2.9	.017	.003	.014	.025	.011
9 "	70.6	0.0	.000	.002	+.002	.023	.021	77.8	0.5	.003	.027	+.024	.021	.045
10 "	71.5	+0.9	+.006	—.001	.005	.015	.020	79.7	+1.4	+.008	.021	.029	.023	.052
11 "	73.1	2.5	.015	+.006	.021	.009	.030	81.5	3.2	.019	.014	.033	.018	.051
12 M.	73.8	3.2	.019	—.001	.018	+.002	.020	82.8	4.5	.027	.013	.040	.011	.051
1 P. M.	74.5	3.9	.023	+.003	.026	.010	.016	84.4	6.1	.037	.002	.039	.001	.040
2 "	74.0	3.4	.020	.014	.034	.017	.017	85.9	7.6	.045	—.019	.026	+.010	.016
3 "	74.6	4.0	.024	.016	.040	.022	.018	85.7	7.4	.044	.018	.026	.022	.004
4 "	74.5	3.9	.023	.017	.040	.027	.013	87.2	8.9	.053	.052	.001	.037	+.036
5 "	74.1	3.5	.021	.005	.026	.032	+.006	85.7	7.4	.044	.042	.002	.034	.032
6 "	73.8	3.2	.019	—.003	.016	.026	.010	83.4	5.1	.030	.036	—.006	.029	.035
7 "	71.7	1.1	.007	.002	.005	.021	.016	80.3	2.0	.011	.010	+.001	.021	.020
8 "	71.5	0.9	.005	.010	—.005	.013	.018	78.1	—0.8	—.001	.018	—.019	.017	.036
9 "	70.8	0.2	.001	.001	.000	—.006	—.006	76.4	1.9	.011	.023	.034	.005	.039
10 "	69.1	—1.5	—.009	.001	.010	.018	.008	75.8	2.5	.015	.003	.018	—.003	.015
11 "	68.4	2.2	.013	.004	.017	.019	.002	75.1	3.2	.019	.002	.021	.004	.017
12 "	68.2	2.4	.014	.001	.015	.011	+.004	74.4	3.9	.024	.000	.024	.006	.018
1 A. M.	67.4	3.2	.019	.002	.021	.005	.016	73.8	4.5	.027	.004	.031	.000	.031
2 "	66.8	3.8	.010	+.002	.008	.000	.008	73.6	4.7	.028	.001	.029	+.003	.032
3 "	67.0	3.6	.021	.006	.015	+.001	.014	73.2	5.1	.031	+.002	.029	.002	.035
4 "	67.0	3.6	.021	.010	.011	—.002	.009	72.5	5.8	.040	.023	.017	—.000	.017
5 "	67.9	2.7	.016	.015	.001	.009	—.008	71.8	6.5	.039	.027	.012	.007	.005
6 "	67.4	3.2	.019	.010	.009	.013	.005	72.4	5.9	.036	.005	.031	.021	.010
Mean.	70.6					29.88		78.3					29.891	

MID-WINTER HORARY CURVES.

Hour.	Yerba Buena, January, 1871. (Means of thirty-one days observations.)							Willet's Point, N. Y., January, 1870. (Means of twenty-seven days observations.)						
	Temp.	Var'n. from Mean.	w	v	$(w+v)$	h	z	Temp.	Var'n. from Mean.	w	v	$(w+v)$	h	z
	°	°	″	″	″	″	″	°	°	″	″	″	″	″
7 A. M.	42.2	—3.9	—.023	+.030	+.007	—.017	—.024	34.0	—4.3	—.026	+.035	+.009	—.016	—.025
8 "	43.5	2.6	.015	.025	.010	.016	.026	35.1	3.2	.019	.026	.007	.023	.030
9 "	45.4	0.7	.004	.014	.010	.036	.040	39.2	+0.9	+.005	.002	.007	.034	.041
10 "	46.9	+0.8	+.005	—.002	.003	.052	.055	42.0	3.9	.022	—.029	—.007	.043	.036
11 "	48.7	2.6	.015	.008	.007	.045	.052	44.6	6.3	.038	.047	.009	.033	.024
12 M.	50.0	3.9	.023	.017	.006	.017	.023	45.7	7.4	.044	.050	.006	.003	+.003
1 P. M.	51.3	5.2	.031	.014	.017	+.010	.007	46.3	8.0	.048	.055	.007	+.017	.024
2 "	51.5	5.4	.032	.027	.005	.024	+.019	45.2	6.9	.041	.046	.005	.023	.028
3 "	50.8	4.7	.028	.035	—.007	.027	.034	43.7	5.4	.032	.039	.007	.030	.037
4 "	49.4	3.3	.020	.016	+.004	.023	.019	41.8	3.5	.021	.029	.008	.025	.033
5 "	48.4	2.3	.014	.013	.001	.027	.026	40.7	2.4	.014	.020	.006	.020	.026
6 "	47.4	1.3	.008	.009	—.001	.031	.032	38.3	0.0	.000	.008	.008	.013	.021
7 "	46.9	0.8	.005	.008	.003	.021	.024	37.1	—1.2	—.007	+.004	.003	.010	.013
8 "	46.0	—0.1	—.001	.011	.012	.012	.023	36.6	1.7	.010	.009	.001	.000	.001
9 "	45.4	0.7	.004	.009	.013	.004	.017	36.0	2.3	.014	.012	.002	—.008	—.006
10 "	44.8	1.3	.008	.003	.011	—.004	.007	35.7	2.6	.015	.016	+.001	.003	.004
11 "	43.8	2.3	.014	—.008	.006	.003	.009	35.1	3.2	.019	.021	.002	+.004	+.002
12 "	43.7	2.4	.014	.004	.010	.000	.010	34.7	3.6	.021	.023	.002	.011	.009
1 A. M.	43.8	2.3	.014	.005	.009	+.003	.013	34.5	3.8	.023	.027	.005	.009	.004
2 "	43.7	2.4	.014	.008	.006	—.003	.003	34.3	4.0	.024	.025	.001	—.001	—.002
3 "	43.3	2.8	.017	.017	.000	.002	—.002	34.4	3.9	.023	.027	.004	.001	.005
4 "	42.9	3.2	.019	.014	.005	.000	+.005	34.4	3.9	.023	.029	.006	+.000	.006
5 "	42.9	3.2	.019	.015	.004	+.007	.011	34.4	3.9	.023	.032	.009	.002	.007
6 "	42.7	3.4	.020	.017	.003	.006	.009	34.2	4.1	.024	.035	.011	—.001	.010
Mean.	46.1			.257		30.078		38.3			.209		30.029	

Horary Barometric curves & their Components.

M Midnight M Midnight

Fig I. West Point, July, 1871.

Fig III. Yerba Buena Cal. January, 1871.

.050 .040 .030 .020 .010 .000 .010 .020 .030 .040 .050

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Fig. II. Willets Point, July, 1870.

Fig. IV. Willets Point, January, 1870.

.050 .040 .030 .020 .010 .000 .010 .020 .030 .040 .050

Horary Barometric curve =

Force of Vapor Component =

Change in Weight =

Resistance of Inertia =

THE PRACTICE

OF

TERRESTRIAL MAGNETICS.

READ BEFORE THE ESSAYONS CLUB OF THE CORPS OF ENGINEERS,

JUNE 24, 1872;

BY

CAPTAIN CHARLES W. RAYMOND,
CORPS OF ENGINEERS.

NO. XXIV. PRINTED PAPERS.

Printed on the Battalion Press.
Corpl. Carmichael & Pvt. Redfield, Printers.

ERRATA.

Page 9, 3rd line, first word. For *siderial* read *sidereal.*

Page 11, 8th line, first word. For *Adjustment* read *Adjustments.*

Page 17. Insert the following paragraph before "*Determination of the Total Intensity.*"

DETERMINATION OF THE HORIZONTAL INTENSITY.

Computation. This value is computed by the formula

$$X = \sqrt{\frac{v}{d}}$$

in which $v = mX$ and $d = \frac{m}{X}$. The value of the magnetic moment of the deflecting magnet may also be obtained from the formula

$$m = \sqrt{v\,d}$$

These determinations are illustrated in *Example* 8.

Page 28, last line. After the word *position* insert a *comma.*

Page 33. The value of *log* $\frac{m}{X}$ which should have been employed is 8.95174. The following are the resulting values: $m = 0.24754$, *log* $X = 0.44190$, $X = 0.27663$.

THE PRACTICE OF TERRESTRIAL MAGNETICS.

A paper read before the "ESSAYONS CLUB" of the Corps of Engineers, on June 24, 1872, by Capt. Charles W. Raymond, Corps of Engineers.

On a previous occasion, I had the pleasure of submitting to the Club a paper on the *Theory of Terrestrial Magnetics*, in which I explained methods of deducing formulas by means of which local magnetic elements may be determined from observations with modern field magnetical instruments. In pursuance of the plan then indicated, I now lay before you a paper on the *Practice of Terrestrial Magnetics*, which consists of a description of the field instruments usually employed on magnetic surveys in the United States, with instructions for their adjustment and manipulation and for the general conduct of the observations; and forms of record and computation which may be employed in actual field-work.

THE OBSERVATORY.

The site for the magnetic observatory should be carefully selected in a place free from local attraction. For the observatory itself a tent may be employed. The irons should be removed from the poles.

The instruments are usually furnished with tripods; but it is much better when practicable to employ sound posts, set firmly in the ground, which should be levelled at a convenient height, so that the observer may sit at the instrument while making his experiments.

Before entering the observatory the observer should remove from his person all metallic articles, such as a watch, keys, buttons, knives etc., which may attract the magnets.

Two instruments are usually employed in magnetic surveys in the United States:—the *Theodolite Magnetometer* and the *Dip Circle*. The first is used in determining the magnetic declination and its variations, and the horizontal component of the earth's magnetic intensity; the second, in determining the magnetic inclination or dip, and, in special cases, the relative total intensity.

THE THEODOLITE MAGNETOMETER.

This instrument, in its best form, as constructed by Würdemann after designs by Prof. J. E. Hilgard, U. S. Coast Survey, is represented in Plate I. It consists essentially of a horizontal limb A A, mounted as in the ordinary theodolite, which supports a frame B B, carrying a telescope T, a wooden magnet-box C C, and a suspension tube D. Two or more collimator-magnets of different lengths, accompany the instrument. In this paper I shall assume that there are two of equal weight, which will be designated as the *long* and the *short* magnet.

The graduated arc on the horizontal limb is read by means of two opposite verniers moving with the frame B B, one of which, with its reading-microscope, is shown at E. It is levelled by means of a circular level, a portion of which is shown at F. The telescope is supported by the arms B B. One of the Y's may be slightly elevated or depressed by turning the adjustment-screw H. The horizontal axis of the telescope may be levelled by means of the striding-level L. The telescope is provided with cross-wires, and may be adjusted at stellar focus by moving the tube which carries the eye-piece.

The wooden magnet-box is fixed in its position by the screws G G. It is provided with wooden side-pieces, one of which is removed in the figure. They fit upon pins K K, and are held in position by screws. They serve to close the box, and prevent disturbances from motions of the air. At the ends of the box are two small glass windows M M. These are usually provided with shutters having narrow observing slits, which are used to modify the light when desirable. They are not shown in the figure. The box is provided with a copper lining N, which may be removed at pleasure.

The glass suspension-tube is fixed in the top of the magnet-box. It is surmounted by a brass ring having a shoulder upon which the brass torsion-circle O turns like the cover on a pill-box. The torsion-circle is graduated, and there is an index engraved upon the ring. The brass bar P, passing through the top of the torsion-circle, is moved up and down in the direction of the axis of the tube by means of the screw Q. In its lower extremity is a small triangular hole in which one end of the suspension-thread is made fast.

The suspension thread consists of one or more filaments of unspun silk, the number depending upon the weight to be suspended. Its lower end is fastened to the stirrup, which is shown at R on the right side of the figure and also within the box. The stirrup is usually open on one side for convenience in suspending the magnet.

One of the magnets is shown at S, suspended in the stirrup. It consists of an accurately turned, magnetized, cylindrical steel tube. One end is closed by a plain glass on which is engraved a delicate scale, almost invisible to the naked eye. The other end, which must be nearest the telescope when the magnet is suspended, contains a lens the focal distance of which is equal to the length of the magnet. When the scale is illuminated, the lens bends the rays parallel to each other, and the divisions will be distinctly visible through the telescope when the latter is adjusted to stellar focus. The scale-glass is mounted in a brass ring which admits of a motion to or from the lens by a screw cut in the interior of the magnet in which it turns. A second ring-screw follows and clamps it when in the right position. The scale usually consists of twenty-one vertical parallel lines. They are not numbered, but are read from apparent left to right, the first line being 0, the second 5, the third 10, etc., up to 100. Intervals between the divisions are estimated.

The concave mirror T serves to throw the light through the magnet and telescope. The counterweight W counterbalances the weight of the telescope. It also serves to support a small brass lamp or a candle for illuminating the magnet during night observations.

The deflection-bar U is held in its place at right-angles to the axis of the telescope by the screws V V. It is only in position during experiments of deflection. It is graduated in feet and decimals of a foot. On it slides the carriage X, which carries the deflecting magnet.

The inertia-ring, which is of brass or bell-metal, is shown on the left of the figure resting upon the blocks Z Z, by means of which it is balanced on the suspended magnet.

In addition to the apparatus shown in the figure, each instrument should be furnished with a brass detorsion-cylinder of the same weight as the magnet to be suspended; a reflector for illuminating the wires during determinations of the astronomical meridian; a small thermometer; two packing-blocks which fit closely on each side of a magnet in the box, and prevent it from shaking about when the instrument is packed; and a small screw-driver which may be slightly magnetized and used in quieting the suspended magnet.

As before indicated, this instrument is employed in two independent sets of determinations. It is used as a *Declinometer* to measure the local magnetic declination and its variations, and as a *Magnetometer*, to determine a component of the earth's local magnetic force. The determinations may, therefore, be conveniently considered under two heads:—*Determinations with the Declinometer* and *Determinations with the Magnetometer.*

DETERMINATIONS WITH THE DECLINOMETER.

The method of determining the local magnetic declination is in outline as follows. The instrument being in adjustment, and the long magnet being suspended in the box, the telescope and box are turned in azimuth until the light can be thrown through the magnet by means of the mirror, and the vertical wire of the telescope is seen nearly coinciding with the *scale-zero* or scale-division corresponding with the magnetic axis. The instrument is then clamped, and the coincidence of the wire and scale-zero is perfected by means of the tangent screw. The verniers of the horizontal limb are then read, a mean of which is the reading of the instrument. The instrumental reading of the astronomical meridian having been determined, the difference of these readings, properly corrected, is the magnetic declination. The variations of this angle may then be observed on the magnet-scale.

DETAILS.

Adjustments of the Declinometer. The adjustments of the declinometer are seven in number. They will be described in the order in which they should be made.

1. *To level the horizontal limb.* The instrument having been placed on the tripod or post and the copper lining removed from the box, turn the foot-screws in opposition in the usual way until the bubble of the level stands at the centre in all azimuths. If this cannot be accomplished, then the position of the level itself must be adjusted by loosening or tightening one of the screws by which it is fastened to the instrument.

2. *To level the rotation-axis of the telescope.* Place the striding-level on the pivots. Note the position of the bubble. Reverse the level on the pivots and again note the position of the bubble. If the indications are the same in both cases, the level itself is in adjustment, and the axis may be levelled by raising or lowering one of the pivots by means of the screw H, until the bubble stands at the centre. If the indications are not the same, the error must be corrected one half by means of the screw H, and one half by means of the adjusting-screw shown at the end of the level. The level is then reversed and the operation repeated until the adjustment is completed.

3. *To make the vertical-wire of the telescope truly vertical.* Turn the intersection of the wires upon a well-defined, distant point. Move the telescope about its rotation-

axis, and see if the wire covers the point throughout its length. If it does not, make it do so by means of the cross-wire adjusting-screws.

4. *To reduce the collimation-error of the telescope.* Turn the intersection of the wires upon a well-defined, distant point. Reverse the telescope in the Y's. If the vertical wire does not cover the point in this position, correct the error one half by means of the cross-wire adjusting-screws, and one half by moving the instrument in azimuth. Reverse again, and repeat the operation until the vertical wire covers the point in both positions of the instrument.

After this adjustment the second adjustment should be again examined.

5. *To suspend the magnet horizontally.* Suspend the stirrup by as few filaments as possible. For the usual load four or five will be required. If the very light magnets recently introduced in the Coast Survey are employed, one will be sufficient. Tie the knots firmly in order to prevent slippage in the determinations of torsion. Place the magnet in the suspended stirrup. Turn the instrument in azimuth until the axes of the telescope and magnet are approximately in the same vertical plane. Move the balancing-ring until the magnet appears to be horizontal. If the magnet and telescope are both approximately horizontal, and their axes approximately in the same vertical plane, the light may be reflected through them by means of the mirror. The position of the balancing-ring should be carefully preserved throughout the observations and experiments.

6. *To adjust the magnet-scale to the stellar focus of its lens.* Turn the telescope upon the sun or a star, and adjust it to perfectly distinct vision. Without changing the focus, turn the telescope upon the suspended magnet. Screw the ring carrying the scale in or out until the scale is seen with perfect distinctness. Clamp the ring.

This adjustment is not often required, but it should be occasionally examined. After it the fifth adjustment should be again examined.

7. *To bring the lines of detorsion and collimation into the plane of the magnetic meridian.* The line of detorsion is the direction in which the torsion of the suspension-thread acts. The line of collimation having been brought near the plane of the magnetic meridian by the last adjustment, remove the suspended magnet and place the brass detorsion-cylinder in the stirrup. Let it rotate until it assumes its natural position of rest. Bring the axis of the cylinder, by estimation, into the plane of the magnetic meridian, by turning the torsion-circle. Remove the cylinder and suspend the long magnet. The suspended magnet may be readily quieted, after a little practice, by holding some article which attracts its pole at the side of the box from which it is moving, and rapidly shifting it to the other side just before the motion changes in direction.

For this purpose the magnetized screw-driver may be employed. The magnet having become steady, move the instrument in azimuth until the telescope is in line with it. Adjust the mirror so that the scale is distinctly visible. Revolve the magnet in the stirrup until the scale-divisions are parallel with the vertical wire of the telescope, and quiet it. Turn the instrument in azimuth until the vertical wire of the telescope bisects the scale-zero, if it has been determined. If not, it should be determined at this point by the method hereafter described. The line of collimation is now in the direction of the magnetic axis, and nearly in the plane of the magnetic meridian. Remove the long magnet and suspend the short magnet. Turn the torsion-circle until the vertical wire of the telescope coincides with the scale-zero. Remove the short magnet and suspend the long magnet. Move the instrument in azimuth until the vertical-wire of the telescope coincides with the scale-zero.

The lines of collimation and detorsion are now in the plane of the magnetic meridian. The time, temperature, readings of the verniers and the reading of the torsion-circle should be recorded.

This method requires that the magnets employed should be of equal weight. With the detorsion-cylinder alone the plane of detorsion may be determined to within about one degree, an error which does not seriously affect the accuracy of the observed declination. This determination would, doubtless, be sufficiently accurate for ordinary field-work.

Constants of the Declinometer. Two constants must be determined for each magnet which is to be employed in the observations. They are (1) *the angular value of one interval of the magnet-scale*, and (2) *the zero of the magnet-scale.*

1. *The angular value of one interval of the magnet-scale.* This value may be determined at any convenient time and place. Once ascertained it is unchangeable for the same magnet.

The instrument is approximately levelled. The magnet is suspended and turned in the stirrup until the divisions of its scale are exactly parallel with the vertical-wire of the telescope. It is then "jammed" in its position and the suspension-thread is slackened, so that the instrument may be moved in azimuth without disturbing the magnet. A convenient method of jamming the magnet is to place it in a groove cut across a thin strip of wood which is passed through the box and supported horizontally at the proper height by means of blocks independent of the instrument. The distance from the scale to the object-glass of the telescope should be exactly the same as when the magnet is suspended.

The instrument is now turned in azimuth until the vertical-wire of the telescope exactly coincides with a division of the scale. The verniers are then read, and the readings and number of the scale division recorded. The instrument is again turned in azimuth until the vertical-wire of the telescope coincides with another scale division, which should be distant from the first about half the length of the magnet-scale, and the vernier readings and number of scale division are recorded as before. This operation is repeated over different parts of the scale until a sufficient number of observations have been obtained. The difference between the vernier-readings of each pair, divided by the corresponding number of scale-intervals passed over, gives a single determination of the angular value of one interval of the scale. The method of recording and reducing the observations is illustrated in *Example* 1.

2. *The zero of the magnet-scale.* This is generally constant for the same magnet, but as it is liable to change by accident, it should be occasionally redetermined.

The instrument having been adjusted, and the magnet having been suspended with its scale-divisions parallel with the vertical-wire of the telescope, turn the instrument in azimuth until the vertical-wire coincides with a division near the middle of the scale, and record the scale-number. Invert the magnet by turning it over in the stirrup; make the scale-divisions parallel to the vertical-wire; quiet the magnet and record the reading of the scale in this position. Move the instrument slightly in azimuth and record the corresponding scale-reading. Invert the magnet and record the scale-reading corresponding to this position. Repeat this operation until three or four readings with the scale erect, and as many with the scale inverted, have been obtained. A combination of these readings determines values of the reading of the scale-zero, a mean of which is the adopted value.

These observations should, if practicable, be made about the epoch of the day when the magnet is stationary. The zero must be determined for each magnet employed. The record and reduction is illustrated in *Example* 2.

Instrumental Correction of the Declinometer. Since the effect of the torsion of the suspension is to make the observed angle less than the true angle of declination, it is necessary to determine a coefficient which will increase the observed angle so as to make it equal to the true one. This is called the *Coefficient of torsion*. This coefficient should be determined frequently, as it is liable to change; but if the torsion is well taken out in adjustment, this correction may be neglected in field declinations without serious error.

The long magnet being suspended, and the instrument being in adjustment for observations of declination, record the readings of the scale and torsion-circle. Turn the

torsion-circle through an angle of 90° ; quiet the magnet and record this difference of arc and the readings of the circle and scale. Turn the torsion-circle through an angle of 180° in the reverse direction ; quiet the magnet and record as before. Finally, turn the torsion-circle back to its original position and repeat the readings and record.

The methods of making the record and reduction are shown in *Example* 3.

Computation. The coefficient of torsion is represented by the expression $1 + \frac{H}{F}$, and is computed by means of the formula

$$\frac{H}{F} = \frac{\alpha'}{\omega - \alpha'} \quad \text{- - - - - - - - - - - - - (4)} *$$

in which α' represents the difference in scale-readings (reduced to arc) corresponding to a change of direction of the magnet caused by twisting the suspension-thread through a large angle ω, usually taken at 90°. The "mean for 90°", deduced as shown in the example, is of course the value employed.

For convenience the coefficient of torsion is usually applied to the angular value $[\alpha]$ of one interval of the magnet-scale.

Determination of the Astronomical Meridian. At some convenient time while the instrument is in position, the intersection of the cross-wires of the telescope should be turned upon some point the astronomical azimuth of which is known or can be subsequently determined, and the readings of the verniers recorded ; or the vernier-readings of the astronomical meridian may be determined directly. In the latter case, the readings corresponding to some fixed point should be noted, so that the meridian may be readily redetermined should the instrument be removed and again placed in position ; and also in order to detect any accidental change in adjustment.

In determining the vernier-readings corresponding to the astronomical meridian, the following method may be employed.

Remove the magnet-box and place the reflector on the end of the telescope. Turn the telescope on *Polaris* and arrange the light so that the wires are distinctly visible. Note the instant of its bisection by the vertical-wire with a chronometer the error of which is known, and the corresponding reading of the horizontal limb. Repeat the observation several times. Reverse the telescope in the Y's, and make a similar set of observations with the rotation-axis in this position.

The record and reduction of these observations is illustrated in *Example* 4.

* Numbers in parentheses refer to the equations in my paper on the *Theory of Terrestrial Magnetics*, No. XX, Printed Papers of the Essayons Club.

Computation. A mean of the observed times and a mean of the corresponding circle-readings are employed. The right ascension of Polaris being subtracted from the siderial time of observation, the hour angle is obtained. The azimuth of *Polaris* (counted from the north) may then be computed by the following formula :

$$\tan A = \frac{\sin t}{\cos \varphi \tan \delta - \sin \varphi \cos t}$$

in which t is the hour angle of Polaris, φ the latitude and δ the star's declination. The reading of the magnetic meridian is obtained by applying the azimuth of Polaris with the proper sign to the mean reading of the horizontal limb obtained from the observations.

Observations of Magnetic Declination. The preliminary adjustments and determinations having been made, the instrument is left in position for observations of the diurnal variations in declination. At some time early in the morning the north end of the magnet attains its most easterly position, which is called the *morning eastern elongation.* The record of scale-readings must be commenced early enough to include this elongation. When this point is fairly passed, or the north end of the magnet has fully commenced its westerly motion, the readings may be discontinued until about noon, when they must be resumed and continued until the western elongation has been observed, and the easterly motion has fairly set in. The telescope should be reversed at each observation and a mean of the readings in the two positions should be taken. The readings should be made half or quarter-hourly during the periods of observation. The observations of the first day will determine the approximate times of elongation or *turning hours*, in accordance with which the periods of observation are to be subsequently regulated.

The values of the instrumental constants, the coefficient of torsion, and such other information as may be of interest or useful in the final computation, should be tabulated for convenient reference, as shown in *Example* 5.

The method of recording and reducing the observations is illustrated in *Example* 6.

Computation. The difference between the mean of the scale-readings at the elongations and the scale reading of the magnetic axis (zero of magnet-scale) gives the "reduction to axis," which, reduced to arc and applied to the reading of the horizontal limb, gives the reading of the magnetic meridian. The difference between this reading and the reading of the astronomical meridian gives the magnetic declination. To reduce this value to what it would have been had the mean of *hourly* observations been taken,

instead of the mean of observations at the elongations, a small correction must be applied. In determining this correction, the following tabular quantities,* which were obtained from the Girard College observations, may be employed.

	f				
January	−0.089	May	−0.013	September	−0.044
February	−0.040	June	+0.010	October	−0.096
March	−0.019	July	+0.005	November	−0.096
April	−0.068	August	−0.023	December	−0.154

For the value of the magnetic declination we have the formula

$$\delta = \delta' \pm \alpha\left(1 + \frac{H}{F}\right) \text{ - - - - - - - - - - - - } (3)$$

in which δ' represents the declination at the time of adjustment and α, the observed change in the value of δ. In order to adapt this formula to purposes of computation it may be written as follows:

$$\delta = \delta' \pm \alpha\left(1 + \frac{H}{F}\right)(e - s + f\,r)$$

in which α represents the angular value of one interval of the magnet-scale; e, the mean of the scale-readings at the elongations, and r, the difference between them or *daily range*; s, the scale-reading of the magnetic axis (zero of magnet scale) and f, a factor taken from the above table. The quantities e, s, and r are expressed in intervals of the magnet scale.

A mean of three or four daily values of the declination, taken near the middle of the month, is adopted as the monthly mean.

DETERMINATIONS WITH THE MAGNETOMETER.

The instrument is employed as a magnetometer to determine the horizontal component of the intensity of the earth's magnetism. For this purpose, two distinct series of experiments are required,—*Experiments of Oscillation* and *Experiments of Deflection*—each of which determines the value of a function of the quantity required, and of the magnetic moment of the magnet employed.

* Report of observations at Capitol Hill, Washington, by Chas. A Schott, Assistant U. S. Coast Survey.

EXPERIMENTS OF OSCILLATION.

These experiments consist essentially in suspending a magnet horizontally in the plane of the magnetic meridian, causing it to oscillate through a small arc, and determining the time of a single oscillation. This time being corrected, and substituted in the proper formula, the value of the product of the magnetic moment of the suspended magnet and the horizontal intensity of the earth's magnetism is obtained therefrom.

DETAILS.

Adjustment of the Magnetometer for Oscillation. The adjustments are the same as those of the declinometer; but, as it is not necessary for these experiments to remove the whole of the torsion, the suspension of the short magnet in the fifth adjustment may be dispensed with. The copper lining should be removed from the box.

Constants of the Magnetometer for Oscillation. Two constants must be determined for the proper computation of the product of the magnetic moment of the suspended magnet and the terrestrial horizontal intensity. They are (1) *the moment of inertia of the suspended magnet and stirrup*, and (2) *the change in the magnetic moment of the suspended magnet corresponding to a change of one degree in temperature.*

1. *Moment of inertia of the suspended mass.* This constant being once determined is unchangeable for the same magnet and stirrup, at the temperature corresponding to the time of determination, unless the position of the balancing ring *s* be changed. At any other temperature, a small correction must be applied for changes in the dimensions or form of the suspended mass.

In order to determine the value of this constant, the moment of inertia of the inertia-ring must be first computed. For this purpose, accurate measurements of the outer and inner radii of the ring (in decimals of a foot), and the weight of the ring (in grains) are required. These data are usually furnished by the maker.

The instrument being in adjustment with the long magnet suspended, and the thermometer being placed near the box, the magnet is made to oscillate, and the time of a single oscillation is determined in accordance with the method hereafter to be described. The corresponding temperature must be recorded.

The inertia-ring is now balanced upon the suspended magnet as follows: The magnet is removed, and the stirrup raised by turning the screw Q. The balancing blocks are placed in position in the box beneath the stirrup. The inertia-ring is passed over the stirrup and held with one hand, while the long magnet is suspended, and adjusted with its scale-divisions parallel to the vertical-wire of the telescope, with the other. The magnet is then lowered into its place in the box, and the ring is carefully adjusted in its position over it. The magnet and ring are then raised by slowly turning the screw Q.

The box is then closed, and the magnet, thus loaded, is again made to oscillate, and the time of a single oscillation is determined as before. The temperature is again recorded.

This determination is illustrated in *Example* 7.

Computation. This constant is computed by means of the formulæ

$$K = K'' \frac{T^2}{T'^2 - T^2} \quad \text{- - - - - - - - - - - - (9)}$$

$$K'' = \frac{1}{2}\left(r^2 + r'^2\right) w \quad \text{- - - - - - - - - - - (10)}$$

in which

K = required moment of inertia of the suspended mass.

K'' = moment of inertia of the ring.

T = corrected time of a single oscillation of the unloaded magnet.

T' = corrected time of a single oscillation of the loaded magnet.

r = outer radius of ring in feet.

r' = inner radius of ring in feet.

w = weight of ring in grains.

2. *Change of magnetic moment for* 1° *Fahrenheit.* This value once ascertained may be regarded as unchangeable for several months. It is determined only for the long magnet. To determine it, two complete sets of oscillations are made with the long magnet, at temperatures differing considerably from each other. These temperatures may be created artificially by placing a shallow copper dish beneath the magnet in the box, and filling it alternately with hot water and a freezing mixture. A thermometer must be placed in the box with its bulb as near the magnet as possible. A thermometer having its graduations on the tube itself is very convenient for this purpose. It may be placed in the suspension-tube, by the side of the suspension-thread, or introduced through a hole in the top of the box, the space around it being closed with wax. The temperature must be recorded continuously throughout the experiments.

Since the publication of my first paper, my attention has been called to the fact that another method is now usually employed for the determination of this constant which has some decided advantages over the above. It consists in suspending a second magnet, and submitting it to the action of the magnet whose constant is to be determined, the latter being fixed in position as will be described under the head of *Experiments of Deflection.* The deflecting magnet is contained in a box, so that its temperature

may be varied by covering it with warm or cold water. The box may be emptied by means of a syphon. The observations consist in noting the temperatures and the corresponding angles through which the free magnet is deflected.

The correction depending upon this constant is very small, and may be neglected without sensible error unless there is a variation in temperature of several degrees during the determinations of intensity.

Computation. If the first method (oscillation) is employed the value of this constant is obtained by means of the formula

$$q=2\frac{T_{'}-T_{''}}{T_{''}t_{'}-T_{'}t_{''}} \quad - - - - - - - - - - - \quad (15)$$

in which q represents the required constant, and $T_{'}$ and $T_{''}$ the times of single oscillations corresponding to the temperatures $t_{'}$ and $t_{''}$.

If the second method (deflections) is employed, the following formula* must be used

$$q=\frac{\sin\,(a_{'}-a_{''})}{(t_{'}-t_{''})\,\tan\,\frac{1}{2}\,(a_{'}+a_{''})}$$

in which $a_{'}$ and $a_{''}$ are the corresponding angles of deflection.

Instrumental Correction of the Magnetometer for Oscillation. *Correction for torsion.* The coefficient of torsion must be determined in accordance with the method explained in connection with determinations of declination.

Determination of the Product of the Magnetic Moment of the suspended Magnet and the Horizontal Intensity. The experiments necessary for this determination consist essentially in suspending a magnet, causing it to oscillate horizontally through a small arc, and ascertaining by observation the average time of a single oscillation.

The instrument being in adjustment with the long magnet suspended, and the vertical-wire of the telescope being near the middle of the scale, cause the magnet to oscillate in a horizontal plane by attracting or repelling one of its poles. The impulse should be sufficient to make the magnet oscillate beyond the limits of the scale for at least ten minutes, as steadiness of motion is thus acquired. All vertical oscillations should be carefully checked. When the amplitude of oscillations is reduced to the limits of the scale, read the scale at the ends of an oscillation. A mean of these readings determines the zero, or point at the passage of which the times are to be noted. If this point does

* Lamont's Handbuch des Magnetismus, page 390.

not coincide with a scale-division, turn the instrument slightly in azimuth and redetermine the zero. A few trials will give the required coincidence.

The intervals corresponding to about 400 vibrations should now be noted in the following way. Note the approximate interval corresponding to six oscillations. This is done for convenience in predicting the time when it is necessary to look out for the passage of the zero over the vertical wire. The instant of passage is then noted at every 6th oscillation up to the 60th; then at the 100th, 200th and 300th; then at every 6th oscillation up to the 360th, and finally, at the 400th. For convenience the approximate time of ten oscillations may be computed at the 60th. Time being noted only at the even oscillations, there will be little danger of observing the wrong one, since for the oscillations to be taken the magnet will always move in the same direction. The amplitude of oscillation at the beginning and at the end of the experiments may be noted, so as to determine a correction for the length of the arc of oscillation, but this correction is, in ordinary cases, so small that this is not absolutely necessary. At suitable intervals during the experiments the mean reading of the scale should be observed, since the zero is liable to changes due to variations of declination.

A thermometer should be suspended near the box, and the temperature should be observed at intervals throughout the experiments. The record and reduction of these observations are illustrated in *Example* 8.

Computation. The product of the magnetic moment and the horizontal intensity is computed by means of the formulas

$$m X = \frac{\pi^2 K}{T^2} \quad - - - - - - - - - - - - \quad (8)$$

$$T^2 = \left(T'\left(1 - \frac{r}{86400}\right)\right)^2 \left(1 + \frac{H}{F}\right)(1 - (t' - t)\, q)$$

in which

m = magnetic moment of the suspended magnet.
X = horizontal intensity.
K = moment of inertia of magnet and stirrup.
T' = observed time of a single oscillation.
r = daily rate of chronometer.
$1 + \frac{H}{F}$ = coefficient of torsion.
t' = average temperature during experiments of oscillation.
t = average temperature during experiments of deflection (described hereafter.)
q = temperature constant.

EXPERIMENTS OF DEFLECTION.

These experiments consist essentially in suspending a second magnet and subjecting it to the simultaneous action of the earth's magnetism and that of the first magnet (which has been employed in the experiments of oscillation), the latter being fixed horizontally in such a way that the prolongation of its axis passes through the centre of suspension of the suspended magnet and is perpendicular to its deflected position.

The observations consist in noting the angle of deflection of the suspended magnet and the distance of its centre from the centre of the deflector.

DETAILS.

Adjustments of the Magnetometer for Deflection. Before the adjustment of the instrument, the deflection-bar must be made fast in its position, and the copper lining placed within the box. The declinometer adjustments are then made, after which the short magnet is suspended and the instrument is moved in azimuth until the vertical wire of the telescope coincides with the zero of its scale.

Constant of the Magnetometer for Deflection. It is sometimes necessary to determine, for the pair of magnets employed in these experiments, the value of a constant, which I shall call the *Constant of Free Magnetism.* The correction depending upon this constant may be neglected in practice when there is a considerable difference between the lengths of the magnets. The value of this constant is greatest when the magnets are equal in length, and zero when their lengths are to each other in the proportion of 1 to 1.224.

If it be necessary to determine the value of this constant, the following method is to be employed. Let two sets of deflections be made, in accordance with the method hereafter to be described, at two different distances. The deflections should be made alternately at these distances, and eight or ten corresponding sets should be obtained.

Computation. The following formula is employed in the determination of this constant:

$$P = -\frac{r^2 r'^5 \sin \alpha' - r'^2 r^5 \sin \alpha}{r'^5 \sin \alpha' - r^5 \sin \alpha}$$

in which r and r' represent respectively the less and greater distances between the centres of the magnets, and α and α', the corresponding angles of deflection.

Determination of the Ratio of the Horizontal Intensity to the Magnetic Moment of the Deflecting Magnet. The experiments of deflection should be made at three distances. The first position of the deflector should be about one foot from the suspended magnet; the second, near the extremity of the deflection-bar; and the third

midway between the other two. I shall, for convenience of description, assume the distances to be 1.0, 1.2 and 1.4 ft. respectively.

The short magnet is suspended. The adjustments having been made, the verniers are read and the time is noted, in order to follow the changes of declination during the experiments of deflection. The small thermometer is suspended on or near the box, and the temperature is recorded at each observation. The carriage is then placed on the deflection-bar, either east or west of the suspended magnet, and at a distance of one foot from its centre, and the long magnet is placed upon it. The suspended magnet is then quieted, and the instrument is turned in azimuth until the vertical wire of the telescope coincides with the scale-zero. The time is then noted and the verniers read. The carriage is then moved to a distance of 1.2 ft., and then to a distance of 1.4 ft., and the observation is repeated at each position.

The deflector is then reversed on its carriage, the details are made as before, and the observation is repeated at the distance 1.4 ft., with the deflector in this position. The carriage is then moved in succession to the distances 1.2 and 1 ft., and the observation is repeated at each position.

At the distance 1 ft., the magnet is again reversed on its carriage and the complete set of observations, which has just been described, is repeated, in order to obtain a double set of results.

The deflector, with its carriage, is now removed and placed on the opposite side of the suspended magnet at a distance of 1 ft. A double set of experiments, similar in all respects to that already described, is then made on this side of the suspended magnet.

At suitable intervals during these experiments, special observations must be made to detect and measure changes of declination. To make this determination, the deflector is removed from its carriage, the suspended magnet is quieted, and the instrument is turned in azimuth until the vertical wire of the telescope coincides with the scale-zero. The verniers are then read and the temperature and time noted. These determinations having been made at convenient intervals (say of half-an-hour), we may, by simple interpolation, obtain with sufficient accuracy, corrections for the reduction of the observed angles of deflection to the same declination. Moreover, we are enabled by this method to employ the instrument as a declinometer and as a magnetometer at the same time, in case two instruments are not furnished for use on the survey.

The record and reduction of these experiments is illustrated in *Example* 9.

Computation. The required value is computed by means of the formula

$$\frac{m}{X} = \frac{1}{2} r^3 \sin \alpha \left(1 - \frac{P}{r^2}\right) \quad - - - - - - - - - - \quad (12)$$

in which

m=magnetic moment of the deflector.
X=horizontal intensity.
r=distance between centres of magnets.
a=angle of deflection.
P=Constant of Free Magnetism.

The value must be computed for each distance separately and a mean adopted.

DETERMINATION OF THE TOTAL INTENSITY.

Computation. This value is obtained from the formula

$$\varphi = X \sec \theta \quad - - - - - - - - - - - - - \quad (16)$$

in which X represents the horizontal intensity, and θ, the inclination or *dip*, the method of determining which will be hereafter described.

REMARKS ON THE DETERMINATION OF INTENSITY.

Since we determine from experiments of oscillation and deflection not only the horizontal intensity but also the magnetic moment of the deflecting and oscillating magnet, it is evident that, were this moment unchangeable, we might, after the first determinations, dispense with one set of experiments, and determine the horizontal intensity by oscillations or deflections alone. In point of fact, however, the magnetism of the magnet suffers a gradual diminution; but as this diminution is tolerably uniform, (unless the magnet is subjected to some unusual disturbing cause, such as a severe shock, great heat or contact with iron,) we may in practice determine the magnetic moment once in two or three months and interpolate the change for intervening observations.

The experiments for intensity may be conveniently made immediately after the suspension of the morning observations of declination. After these experiments, the dip may be determined.

THE DIP-CIRCLE.

The instrument usually employed in the United States is represented in Plate II. It consists essentially of a horizontal limb, a vertical circle, an arrangement for the vertical suspension of a magnetic needle, and a magnetic needle of suitable form, provided with an axis at right angles to its length.

The horizontal limb $A\,A$ is supported, in the usual way, on three feet, and is levelled by means of the foot screws $a\,a\,a$, and the level L. The vernier-plate B carries a vernier over the graduated arc of the limb and is clamped by means of the screw b.

The brass plate $D\,D$, to which the vernier-plate is attached, turns horizontally about the vertical axis of the horizontal limb. At its extremities are two vertical brass pillars $E\,E$, to which is attached the vertical circle $F\,F$, the face of which is perpendicular to the plane of the horizontal limb. The vertical circle is graduated usually to 10′.

A horizontal brass frame $G\,G$ carries the supports for the magnetic needle. They consist of two rectangular pieces of agate $e\,e$, which fit accurately in the frames $f\,f$, and are adjusted by means of the screws $g\,g$. Within the frame $G\,G$ is a second frame $h\,h$, which carries two V's $k\,k$. One extremity of the frame $h\,h$ may be raised a little by turning the pin H, and by this means, the needle, when suspended, may be lifted gently from the agate supports.

The vertical portion of the instrument is covered with a glass case $K\,K$, to which are attached the reading-microscopes $M\,M$.

Two or more needles are usually furnished with each instrument. The needle consists of a long, flat piece of steel shaped as shown at N. An accurately turned axis passes through, and is fastened to the needle, as nearly as possible at its centre of gravity. One extremity of the needle is marked on one side. The marked surface is called the *face*.

Some instruments are also furnished with a "Lloyd's needle," which consists of a needle of the ordinary form, perforated with three small holes, close together near the extremity of each arm. The holes should be at a distance from the centre of about two-thirds the length of the arm, and should coincide with the axis of form of the needle.

Accompanying each instrument are two magnetizing-bars and a magnetizing-box. The bars are of steel, magnetized to saturation, and are five or six inches in length, having a rectangular cross-section. The positive pole of each bar is marked with the letter N. When not in use, these bars are packed parallel to each other, the north end of one being opposite the south end of the other, and pieces of soft iron called *keepers* are placed across the ends. The magnetizing-box is an oblong piece of wood in which is cut a hollow place having the shape of the needle. In this the needle is placed, and held firmly in a horizontal position while being magnetized.

USE OF THE MAGNETIZING-BARS.

The magnetizing-bars are employed in *charging*, *demagnetizing* and *reversing the polarity* of the dipping-needle.

1. *To charge the needle.* Place the needle in the magnetizing-box. Hold a magnetizing-bar vertical in each hand, the lower ends of the bars resting on the face of the needle, close to, and on opposite sides of its axis of suspension, in such a way that the *north*

end of one bar shall rest on the arm whose pole is to be *south*, and the *south* end of the other bar shall rest on the arm whose pole is to be *north*. Incline the upper ends of the bars toward each other until they are in contact. Draw the bars, with pressure, along the surface of the needle, in opposite directions, keeping the upper ends in contact, until they arrive at the extremities of the needle. Raise the bars from the needle. Repeat this operation if necessary. Three touches are usually sufficient. Turn the needle over in the magnetizing-box, and operate on the opposite surface in the same manner. The motion of the bars should be, as nearly as possible, in the direction of the needle's axis of form.

2. *To demagnetize the needle.* The process is the same as in charging, except that the *north* end of one bar is placed on the *north* arm of the needle, and the *south* end of the other bar, on the *south* arm. A single touch on each surface is usually sufficient.

3. *To reverse the polarity of the needle.* Demagnetize the needle, and continue the process until the polarity is reversed. Three touches on each surface are usually sufficient.

DETERMINATIONS WITH THE DIP-CIRCLE.

In the system of experiments and observations which at present occupy our attention the Dip-Circle is employed only in the determination of the magnetic inclination. As explained in my first paper, this instrument is, in special cases, employed as a magnetometer. The limits of this paper will not permit detailed instructions for these experiments, but they will present no difficulties to an observer familiar with the use of the instrument as an inclinometer.

The method of determining the magnetic inclination or *dip* with this instrument is essentially as follows. The face of the vertical circle having been adjusted, as nearly as possible, in the plane of the magnetic meridian, a magnetized dipping-needle is suspended on the agate supports. The readings of the vertical-circle at the ends of the needle are then noted, and a mean of the two results is the required value.

There are three errors involved in the construction of this instrument. First, the magnetic axis of the needle does not accurately coincide with its axis of form. Secondly, the instrumental vertical (line corresponding to circle-reading 90°) does not accurately coincide with the true vertical. Thirdly, the centre of suspension of the needle is not situated exactly at the centre of gravity. The first of these errors is approximately eliminated by reversing the needle on its supports, and taking a mean of the results obtained in the two positions; the second error is corrected by turning the vertical-circle 180° in azimuth and repeating the observations; and the third, by observing with the polarity of the needle reversed, by which means the centre of gravity of the needle is brought

on the opposite side of the centre of suspension. A mean of the results under these varied circumstances is the adopted value.

Other causes of error arise from the fact that the limb of the instrument itself often becomes slightly magnetic, and there are often imperfections in the axis of suspension. To guard against errors due to these causes the inclination should be determined by observations out of the magnetic meridian, in planes at right angles to each other. The difference between the value thus determined and the value determined in the usual way must be applied as a constant correction to subsequent meridian determinations.

By taking a mean of the results from observations with several needles the accuracy of the final result is of course increased.

DETAILS.

Adjustments of the Dip-Circle. The adjustments of the instrument are three in number. They will be described in the order in which they should be made.

1. *To level the horizontal-limb.* The instrument having been placed on its tripod or post, turn the foot-screws in opposition in the usual way, until the bubble of the level stands at the centre in all azimuths.

2. *To suspend the needle in the plane of the face of the vertical-circle.* Raise the Y's by turning the head *H*. Place the needle (which must be previously charged) in the Y's, and lower it gently upon the agate supports. Turn the vertical-circle slowly in azimuth around the entire circle, and see whether the needle plays freely, and whether its face lies in the plane of the face of the vertical-circle in all azimuths. If not, make it do so by raising or lowering one or both of the agate supports by means of the screws *g g*.

3. *To bring the face of the vertical-circle into the plane of the magnetic meridian.* Turn the vertical circle of the instrument in azimuth until the needle is vertical. Record the reading of the horizontal limb. Reverse the needle on its supports; make it again vertical by turning the vertical-circle slightly in azimuth, and record as before. Turn the vertical-circle 180° in azimuth and repeat the double observation as before. A mean of the four readings is the reading of the magnetic prime-vertical, from which the settings for the magnetic meridian are obtained by adding and subtracting 90°.

Set the vertical-circle of the instrument at one of these readings.

The record and reduction of the observations required for the adjustment are illustrated in *Example* 11.

Instrumental Correction of the Dip-Circle. This correction is the difference between the value of the dip determined from observations in the magnetic meridian and the value determined from observations in two planes on opposite sides of the meridian and at right angles to each other.

The instrument being in adjustment, a complete set of experiments must be made in the plane of the magnetic meridian, in accordance with the method hereafter to be described. The vertical-circle is then turned in either direction, about 45° in azimuth, and a similar series of experiments is made in this position of the instrument. The vertical-circle is then turned in azimuth through an angle of 90° in the opposite direction, and in this position of the instrument, the series of experiments is again repeated.

This correction should be determined for each needle employed, and may be regarded as constant for a magnetic survey.

The record and reduction of these experiments is illustrated in *Example* 10.

Computation. The value of this constant is computed by means of the formulas

$$C=\theta-\theta_{,} \qquad \cot^2\theta=\cot^2\theta'+\cot^2\theta'' \quad - \; - \; - \; - \; - \; - \; - \; (23)$$

in which θ' and θ'' represent the observed inclinations in planes at right angles to each other, and $\theta_{,}$ the observed inclination in the plane of the magnetic meridian.

Determination of the Magnetic Inclination or Dip. The instrument having been adjusted in the plane of the magnetic meridian and the needle quieted, record the reading of the vernier of the horizontal limb. Record the polarity of the needle (marked end north, or south), the position of the vertical-circle (face east or west), the position of the needle (face east or west), the readings of the vertical-circle at the two ends of the needle and the temperature Fahrenheit. Raise the needle and reverse it upon its supports; quiet it and repeat the observations. Bring the needle back to its original position and record as before. Reverse it again and repeat the observations.

Turn the vertical-circle 180° in azimuth; quiet the needle and repeat the observations as above.

Remove the needle and reverse its polarity. Suspend it again, and repeat the observations with the circle and needle in both positions, as before.

The record and reduction of these observations is illustrated in *Example* 11.

Computation. The dip is computed by means of the formula

$$\theta=\theta_{,}+C$$

in which $\theta_{,}$ represents the mean of the observed values, and C, the instrumental correction.

CONCLUSION.

It gives me pleasure to avail myself of this opportunity to acknowledge my obligations to Prof. George Davidson, U. S. Coast Survey, who several years ago gave me my first instructions in the practical employment of magnetical instruments. Many details which I have embodied in this paper are due to his skill and experience; and were I able at this late day to distinguish between what I have learned from him and what I have acquired elsewhere, I should not content myself with this general acknowledgement.

My thanks are also due to General C. B. Comstock, Corps of Engineers, Superintendent of the U. S. Lake Survey, who at my request examined these papers before publication, and whose criticisms have resulted in the correction of several errors and inaccuracies.

I am indebted to Prof. Joseph Henry for a set of the publications of the Smithsonian Institution relating to magnetism; to General John G. Parke, Corps of Engineers, for a copy of Magnetical Observations at Capitol Hill, Washington; to Prof. J. E. Hilgard, U. S. Coast Survey, for plates from which the appended outline sketches of instruments have been prepared; and to Prof. Charles A. Schott, U. S. Coast Survey, for information on several points.

EXAMPLES OF RECORD AND COMPUTATION.

NOTE. It was originally my intention to append to this paper a complete set of observations, which I expected to make myself in order to test the foregoing instructions by actual practice. Circumstances, however, have prevented the complete accomplishment of this design; and I have therefore selected the following illustrative examples from such sources as are at my command. With the exception of the instructions for the use of the Dip-Circle, the foregoing instructions have been prepared without using the instrument. Possibly, therefore, inaccuracies and even errors may be found.

CONSTANTS OF THE DECLINOMETER.

EXAMPLE 1.

Determination of angular value of one interval of magnet-scale.

Observations for value of scale of magnet for declinometer.

Station, *Bodega Camp, Sonoma Co., Cal.* Date, *Aug.* 11, 1860. *P. M.*

Observer, *G. D.* Recorder, *H. B. H.*

Readings of Verniers.			Means of Verniers.			Difference in Minutes.	Scale Reading.	Difference of Scale.	Value of 1 Interval.
°	′	″	°	′	″	′			′
29	14	40							
		40	29	14	40		10.0		
27	32	10				102.50		65.0	1.577
		10	27	32	10		75.0		
29	06	50				94.75		60.0	1.579
		60	29	06	55		15.0		
27	39	40				87.25		55.0	1.586
		40	27	39	40		70.0		
28	58	40				79.08		50.0	1.582
		50	28	58	45		20.0		
27	47	50				70.82		45.0	1.574
		60	27	47	55		65.0		
28	51	00				63.17		40.0	1.579
		10	28	51	05		25.0		
27	55	30				55.50		35.0	1.586
		40	27	55	35		60.0		
28	55	30				60.00		38.0	1.579
		40	28	55	35		22.0		
27	52	30				62.92		40.0	1.573
		50	27	52	40		62.0		
29	04	00				71.42		45.0	1.587
		10	29	04	05		17.0		
27	44	30				79.42		50.0	1.585
		50	27	44	40		67.0		
29	11	20				86.83		55.0	1.579
		40	29	11	30		12.0		
27	36	30				94.92		60.0	1.582
		40	27	36	35		72.0		

Mean value of one interval – – $a = 1'.580 \pm 0.001$.

CONSTANTS OF THE DECLINOMETER.

EXAMPLE 2.

Determination of the zero of the magnet-scale.

Scale-zero of Declination magnet.

Station, *Fort Yukon, Alaska.* Date, *Aug.* 12, (*P. M.*) 1869.

Observer, *C. W. R.* Recorder, *C. W. R.*

Position of Scale.	Reading of Scale.	Alternate Means.	Zeros.	Mean Zero.
Erect	45.00			
Inverted	57.00	45.50	51.25	
Erect	46.00	55.50	50.75	50.18
Inverted	54.00	44.75	49.37	
Erect	43.50	55.25	49.37	
Inverted	56.50			

INSTRUMENTAL CORRECTION OF THE DECLINOMETER.

EXAMPLE 3.

Determination of the Coefficient of Torsion.

Station, *Fort Yukon, Alaska.* Date, *Aug.* 13, 1869.
Observer, *C. W. R.* Recorder, *C. W. R.*

Declination magnet suspended.

Circle Readings.	Scale Readings.	Diff. of Arc.	Diff. of Scale.	Mean for 90°.
3.95	51.25	°		
		90	20.75	
30.95	30.50			
		180	49.00	23.56
12.95	79.50			
		90	24.50	
3.95	55.00			

Computation.

	Logarithms.
$\omega = 90° = 324000''.0$	
$a' = 23.^{d}56 = \quad 699.7$	2.84491
$\omega - a' = 323300.3$	5.50961
$\frac{H}{F} = 0.00216$	7.33530
$1 + \frac{H}{F} = 1.00216$	$\frac{H}{F} = \frac{a'}{\omega - a'}$
$a^{*}\left(1 + \frac{H}{F}\right) = 29''.76$	

* $a = 29''.70$

DETERMINATION OF THE ASTRONOMICAL MERIDIAN.

EXAMPLE 4.

Observations for azimuth of Polaris. *

Harrisburg, *Lat.* 40° 16′; *Long.* 76° 53′. *July* 25, 1840.

Telescope Direct.						Telescope Reverse.					
Chron. time.			Circle reads.			Chron. time.			Circle reads.		
h.	m.	s.	°	′	″	h.	m.	s.	°	′	″
1	48	46.0	301	15	15	2	04	06.4	301	19	00
	51	53.8		16	15		08	13.6		20	10
	54	52.0		17	10						
1	51	50.6	301	16	13	2	06	10.0	301	19	35

Mean of times, 1 h. 59 m. 00.3 s.

Mean circle-reading, 301° 17′ 54″.

Computation.

	h.	m.	s.
Chron. fast	5	08	25.4
Chron. time of observation	1	59	00.3
Mean time of observation	8	50	34.9
Corresponding sidereal time	17	05	54.8
R. A. of Polaris	1	02	18.6
Hour angle	16	03	36.2
Azimuth of Polaris (E. of N.)		1°	45′.0
Reading of "		301	17.9
" " Astronomical meridian		299	32.9

* From Prof. Bache's "Magnetic Survey of Pennsylvania," Smithsonian Contributions No. 166.

MAGNETIC DECLINATION.

EXAMPLE 5.

Data for Magnetic Declination.

Fort Yukon, Alaska, August 13, 1869.

1. Angular value of one scale-interval of the declination-magnet - - - - 29″.70
2. Angular value of one scale-interval of the collimation-magnet - - - - 34″.80
3. Scale-zero of the declination-magnet - - - - - - - - - - - - - - 50.20
4. Scale-zero of the collimation-magnet - - - - - - - - - - - - - - 90.20
5. Mean difference of scale-readings for 90° of torsion - - - - - - - - 23.56
6. Angular value of one scale-interval of the declination-magnet corrected for torsion $\left[a \left(1+\frac{H}{F}\right) \right]$ - - - - - - - - - - - - - - - 29″.76
7. The observer at this instrument looks *north*, and an increase of scale-readings denotes a movement of the north end of the magnet to the *eastward.*
8. Readings of verniers corresponding to the astronomical meridian *E.*27° 30′; *W.*207° 30′.
9. Readings of verniers at instant of final adjustment - - *E.*63° 54′; *W.*243° 54′.
10. Readings of verniers corresponding to meridian-mark (south) *E.*29° 00′; *W.*209° 00′.
11. Geographical position of the instrument $\varphi = 66° 33′ 47″$ north; $\lambda = 145° 17′ 47″$ west.
12. Instrument put in position details, observations and record by C. W. R.

MAGNETIC DECLINATION.

EXAMPLE 6.

Record of Observations.

Station: *Washington, D. C.* Date: *June* 15, 1871.
Instrument: *Declinometer No.* 7. Observer: *C. A. S.*
Mark reads *at* 6 *h.* 10 *m. a. m.*, 242° 50′.5 and 62° 49′.5.
Line of detorsion 276°. Magnet *A* suspended, scale *erect.*
Azimuth circle set to 244° 25′.0 and 64° 24′.5.

Time.		Scale reading.		Mean.	
a.	m.	Left.	Right.		
h.	m.	d.	d.	d.	
6	30	11.0	12.8	11.90	Removed torsion weight at 6 h. 15 m., and suspended magnet.
	45	11.8	12.2	12.00	
7	00	12.0	12.3	12.15	
	15	12.2	12.5	12.35	
	30	12.4	12.5	12.45	Maximum.
	45	12.3	12.5	12.40	
8	00	12.1	12.3	12.20	Suspended torsion weight after this observation.
p.	m				
0	15	5.9	6.9	6.40	
	30	6.0	6.6	6.30	
	45	6.2	6.5	6.35	
1	00	6.2	6.3	6.25	Minimum.
	15	6.2	6.3	6.25	
	30	6.3	6.7	6.50	

Pointing on Mark: 242° 50′.0 and 62° 49′.5.

MAGNETIC DECLINATION.

EXAMPLE 6. (*Continued*)

Computation.

Mean reading of E. & W. Elongations	$9^d.35$, and diff. of readings $6^d.20$
Axis of magnet reads	7 .30
Reduction to axis	+2 .05=5′.0
Azimuth circle reads	244° 24′.8
Magnetic meridian reads	244 29 .8
Mark reads	242 49 .9
Mark West of North	4 36 .1 ± 0′.1
Astronomical meridian reads	247 26 .0
Magnetic declination	+ 2 56 .2
Reduction to mean of day	+ 0 .2
Resulting declination, June 15, 1871.	2° 56′.4 West.

We also have on this day, the daily range 15′.1 and the turning hours, about 7 h. 30 m. a. m. and 1 h. 05 m. p. m.

CONSTANTS OF THE MAGNETOMETER FOR OSCILLATION.

EXAMPLE 7.

Moment of Inertia of the suspended Magnet and Stirrup.

Fort Yukon, Alaska, August 16, 1869.

$$K'=\frac{1}{2}\left(r^2+r'^2\right)w\ ; \qquad K=K'\frac{T^2}{T'^2-T^2}$$

r=outer radius of ring in feet	= 0.083290
r'=inner radius of ring in feet	= 0.066708
w=weight of ring in grains	= 507.02
r^2=0.0069372241	$t'-t$= 10°.9
r'^2=0.0044499573	2ε = 0.0000136
$r^2+r'^2$=0.0113871814	log=8.0564162
$\frac{1}{2}w$=253.51	log=2.4039951
T^2=77.440000	log K'=0.4604113
T'^2=35.593156	log=1.5513850
T'^2-T^2=41.846844	ar. co. log=8.3783373
$1+2\varepsilon(t'-t)$=1.00014824	log=0.0000644
	log K=0.3901980

HORIZONTAL INTENSITY.

EXAMPLE 8.

Experiments of Oscillation.

Station, *Fort Yukon, Alaska.* Date, *August* 16, 1869.

Long magnet suspended without load.

Chronometer *Bliss & Creighton*, 1609 *M. T.* Daily rate, (*unknown*).

Observer, *C. W. R.* Recorder, *J. J. M.*

No. of Osc.	Times by Chronometer.	Temp. F.	Diff. of Times.	Remarks.
	h. m. s.	°	°	
0	1 16 05.0	82.5		Approximate time of 6 oscillations at the beginning – – 35 s.
6	16 40.8		35.8	
12	17 16.5		.7	Approximate time of 10 oscillations at the 200th – – – 59 s.
18	17 52.3		.8	
24	18 28.3		36.0	Scale-reading taken just before 200th oscillation to show changes of declination. Reading 65.00 ; Time, 12 h. 15 m. P. M.
30	19 04.0		35.7	
36	19 39.7		.7	Stopped, 1 h. 42 m. P. M.
42	20 15.5		.8	
48	20 51.3		.8	
54	21 27.0		.7	
60	22 02.8		.8	
100	26 01.5	81.0	238.7	
200	35 57.5		596.0	
300	45 47.8	84.5	590.3	

Time of 300 Oscillations, 1782.8

HORIZONTAL INTENSITY.

EXAMPLE 8. (*Continued.*)

Computation.

$$T^2=\left(T'\left(1-\frac{r}{86400}\right)\right)^2\left(1+\frac{H}{F}\right)\left(1-(t'-t)\,q\right)$$

Observed time of 300 oscillations – – 1782.8 s.

Time of one oscillation – – 5.9426 s.

			Logarithms.
q	0.00015	T'	0.77398
$t'-t$	0°.06	T'^2	1.54796
$(t'-t)\,q$	0.000009	$1+\frac{H}{F}$	0.00103
$1-(t'-t)\,q$	0.99991	$1-(t'-t)\,q$	9.99996
	Logarithms.	T^2	1.54895
$\frac{m}{X}$ *	8.92574	$\pi^2 K$	1.38449
mX	9.83554	mX	9.83554
m^2	8.76138	m	9.38069
m	0.24024	X	0.45490

* Experiments of Deflection.

HORIZONTAL INTENSITY.

EXAMPLE 9.

Experiments of Deflection.

Station, *Fort Yukon, Alaska.* Date, *August* 14, 1869.
Observer, *C. W. R.* Recorder, *C. W. R.*
Magnets at right angles to each other.
Long magnet deflecting. Short magnet suspended.

* * * * * * * * * *

Magnet at 1′.09 east and west.

Position of defl.	No. of Obs.	Marked end.	Temp., F.	Verniers E. and W.	Means of Verniers.	Time.	Means corr. for change of declination.	Arc of deflection, semi-arc.
			°	° ′ ″	° ′ ″	h. m. s.	° ′ ″	° ′ ″
E.	3	E.	81.0	71 18 05	161 18 05	2 10 00	161 17 32	
				251 18 05				15 43 52.0
	4	W.	82.0	55 33 00	145 33 00	2 18 00	145 33 40	7 51 56.0
				235 33 00				15 46 00.0
	9	E.	81.0	71 21 00	161 21 00	3 02 00	161 19 40	7 53 00.0
				251 21 00				15 43 15.0
	10	W.	82.0	55 35 00	145 35 00	3 08 00	145 36 25	7 51 37.5
				235 35 00				
							Mean....	7 52 11.2
W.	15	E.	85.5	71 34 00	161 34 00	4 13 00	161 34 09	
				251 34 00				16 04 21.0
	16	W.	87.0	55 30 00	145 30 00	4 22 00	145 29 48	8 02 10.5
				235 30 00				16 06 44.0
	21	E.	84.0	71 36 00	161 36 00	5 22 00	161 36 32	8 03 22.0
				251 36 00				15 55 08.0
	22	W.	85.0	55 42 00	145 42 00	5 35 00	145 41 24	7 57 34.0
				235 42 00				
	Mean for E. and W.....				7 56 36.7		Mean....	8 01 02.2

Remarks.—1h. 34m. p. m.—Turned instrument on 50.18 decl. scale. Verniers, *E.* 63° 51′; W. 243° 51′. Temp., 78°.5 F., (attached.) 3h. 45m. p. m.—Deflector away to show changes of declination. Temp., 87° F. Verniers, E. 63° 49′; W. 243° 49′. 6h. 00m. p. m.—End of experiments. Temp., 82° F. Scale, 58.50. Verniers, E. 63° 54′; W. 243° 54′.

HORIZONTAL INTENSITY.

EXAMPLE 9. (*Continued.*)

Computation.

$$\frac{m}{X} = \frac{1}{2} r^3 \sin a \left(1 - \frac{P}{r^2}\right).$$

		Logarithms.
$a = 7^\circ\ 56'\ 36''.7$	$\sin a$	9.14049
$r = 1'.09$;	r^3	0.11228
$P = O$	$1 - \frac{P}{r^2}$	
	$\frac{1}{2}$	9.69897
0.08948) =	$\frac{m}{X}$	8.95174

INCLINATION.

EXAMPLE 10.

Instrumental Correction of Dip-Circle.

Station, *Willet's Point, N. Y.* Date, *August* 5, 1872.
Observer, *C. W. R.* Recorder, *C. W. R.*
Dip-Circle by Würdemann. Lloyd's needle.
Extra-meridian observations.
Set I. *Settings* - - 22° - - 202°.

Marked end.	Face of Circle.	Face of Needle.	Means of N and S ends.		Means.			Means.			Temp. F.
			°	′	°	′	″	°	′	″	
N	E	E	78	00							
		E	78	00	78	00	00				
		W	77	08				77	37	00	
		W	77	20	77	14	00				
	W	E	78	00							
		E	78	00	78	00	00				
		W	77	37				77	48	00	
		W	77	35	78	36	00				
Mean.								77	42	30	
S	E	E	78	37							
		E	78	37	78	37	00				
		W	78	20				78	28	30	
		W	78	20	78	20	00				
	W	E	78	00							
		E	78	00	78	00	00				
		W	78	38				78	20	30	
		W	77	44	78	41	00				
Mean.								78	24	30	
Resulting inclination [θ'] - - - - -								78	03	30	

INCLINATION.

EXAMPLE 10. (*Continued.*)

Extra-meridian observations.

Set II. *Settings* - - 292° - - 112°.

Marked end.	Face of Circle.	Face of Needle.	Means of N and S ends.	Means.	Means.	Temp. F.
			° ′	° ′ ″	° ′ ″	
N	E	E	76 44	76 42 00	76 16 30	
		E	76 40			
		W	75 50	75 51 00		
		W	75 52			
	W	E	77 52	77 46 00	77 25 15	
		E	77 40			
		W	77 05	77 04 30		
		W	77 04			
Mean.					76 50 52	
S	E	E	77 48	77 49 00	77 39 30	
		E	77 50			
		W	77 30	77 30 00		
		W	77 30			
	W	E	77 34	77 34 30	77 41 30	
		E	77 35			
		W	77 44	77 48 00		
		W	77 52			
Mean.					77 40 30	
Resulting inclination [θ''] - - - - -					77 16 07	

For corresponding meridian observations see next example.

INCLINATION.

EXAMPLE 10. (*Continued.*)

Computation.

$\cot^2\theta = \cot^2\theta' + \cot^2\theta''$ $\qquad C = \theta - \theta_,$

$\theta' = 78^\circ\ 03'\ 30''$	$\log \cot^2\theta' = 8.65058$ - - - - - - - -	0.044728
$\theta'' = 77\ \ 16\ \ 07$	$\log \cot^2\theta'' = 8.70790$ - - - - - - - -	0.051039
	$\log \cot^2\theta = 8.98122$ - - - - - - - -	0.095767
	$\theta = 72^\circ\ 48'\ 10''$	
From next example	$\theta_, = 72\ \ 47\ \ 52$	
	$C = \qquad + 18''$	

NOTE. The symmetry of the needle employed in these observations had been seriously impaired by oxidation. The experiments were made in a room filled with furniture, and no precautions were taken with reference to local attraction. The result shows how completely the above method of making and combining observations eliminates local and instrumental errors.

INCLINATION.

EXAMPLE 11.

Determination of the Dip.

Station, *Willet's Point, N. Y.* Date, *August* 5, 1872.

Observer, *C. W. R.* Recorder, *C. W. R.*

Dip-Circle by Würdemann. Lloyd's needle.

Meridian observations.

Settings for Magnetic Meridian.

Face of Circle.	Face of Needle.	Readings of hor. limb.	
		°	′
S	S	157	27
S	N	158	42
N	S	337	01
N	N	338	12
	Magnetic prime-vertical	157	50
	Settings - - - - -	247	50 - - 67° 50′

Marked end.	Face of Circle.	Face of Needle.	Means of N and S ends.		Means.			Means.			Temp. F.
			°	′	°	′	″	°	′	″	
N	E	E	73	04	73	02	00				
		E	73	00				72	36	30	
		W	72	12	72	11	00				
		W	72	10							
	W	E	72	30	72	29	00				
		E	72	28							
		W	72	49	72	49	00	72	39	00	
		W	72	49							
Mean.								72	37	45	

INCLINATION.

EXAMPLE 11. (*Continued.*)

Meridian observations.

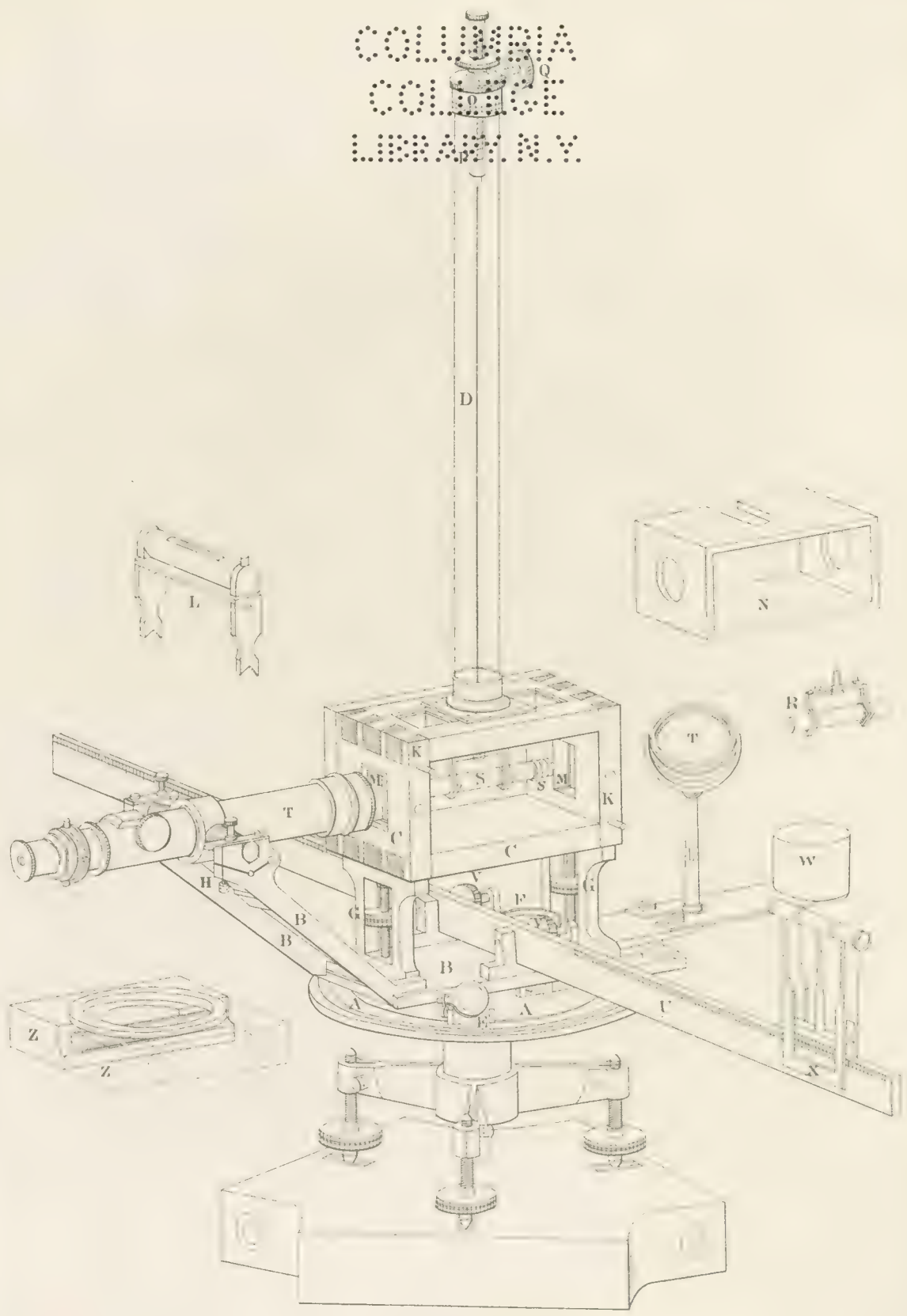
Marked end.	Face of Circle.	Face of Needle.	Means of N and S ends.	Means.	Means.	Temp. F.
			° ′	° ′ ″	° ′ ″	
S	E	E	72 43			
		E	72 45	72 44 00		
		W	73 00		72 55 00	
		W	73 12	73 06 00		
	W	E	72 49			
		E	72 47	72 48 00		
		W	73 14		73 01 00	
		W	73 14	73 14 00		
Mean.					72 58 00	
Resulting inclination [$\theta_,$] – – – – –					72 47 52	

Computation.

$$\theta = \theta_, + C$$

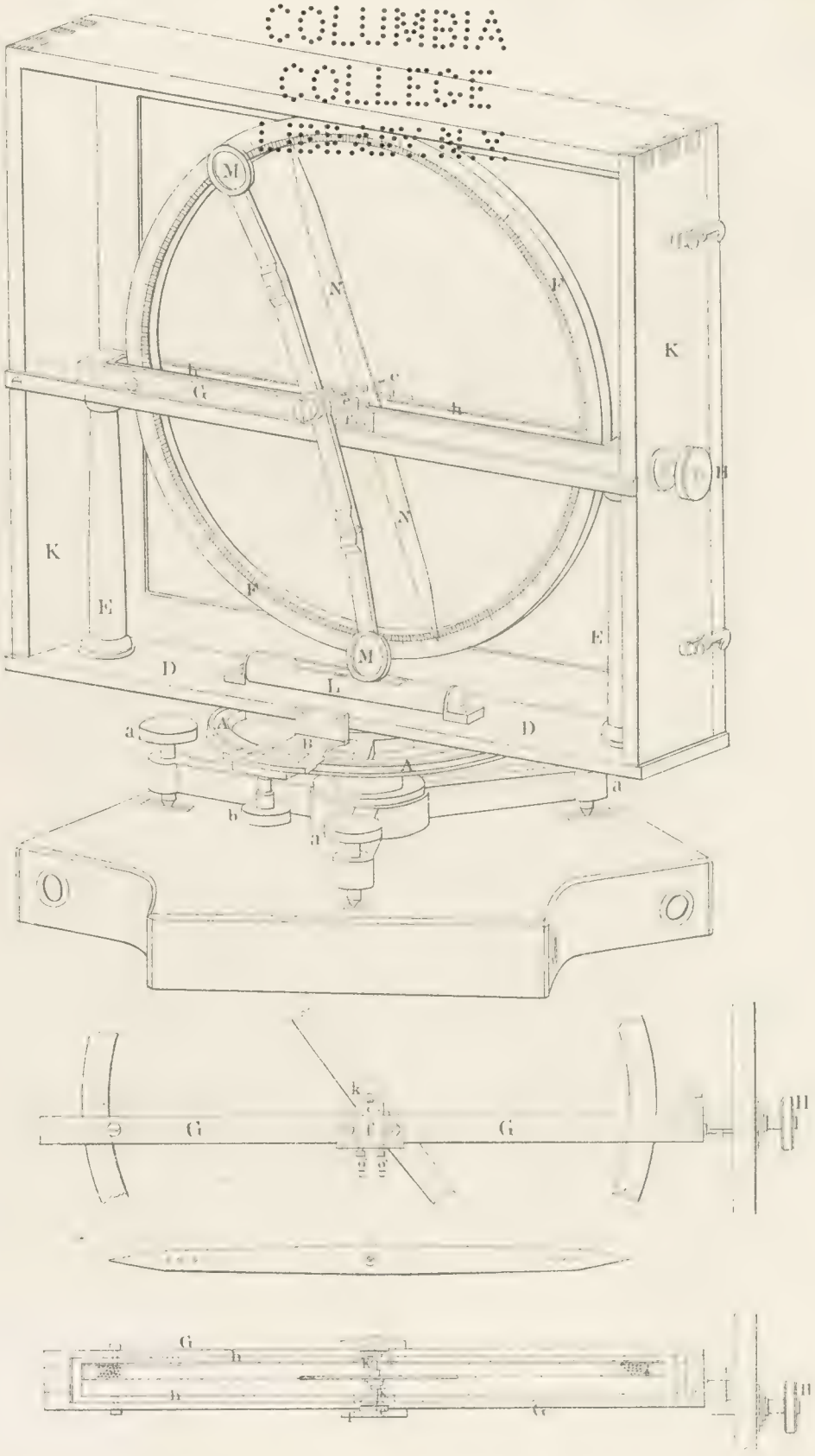
$\theta_, = 72°\ 47'\ 52$ $C = +18''$ $\theta = 72°\ 48'$.

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NOTES

ON

HARBORS OF THE GREAT LAKES.

READ BEFORE THE ESSAYONS CLUB OF THE CORPS OF ENGINEERS,

DECEMBER 23, 1872;

FROM

BVT. COL. D. C. HOUSTON,
MAJOR OF ENGINEERS.

NO. XXV. PRINTED PAPERS.

Printed on the Battalion Press.
Corpl. Carmichael & Pvt. Redfield, Printers.

NOTES ON LAKE HARBORS.

A paper read before the "ESSAYONS CLUB" of the Corps of Engineers, on December 23, 1872, from Bvt. Col. D. C. Houston, Major, Corps of Engineers.

The harbor improvements on the great lakes which have been carried on so extensively during the past few years, to the great benefit of commerce, have assumed at the present time the character of a system, the principles of which it is the object of this paper to state and illustrate in part. The lake harbors are of two classes first, those which are entirely artificial and second, those which are in part natural and in part artificial. The first class embraces those where no protection whatever is afforded against prevailing on shore winds by the line of the coast or by natural inlets, in which case all the protection afforded is by breakwaters.

The second class embraces first, those indentations in the coast which afford protection from certain winds but not all and require a partial protection and second, natural inlets or rivers which require improvement to enable vessels of the larger class to enter them safely. The general principle involved in the construction of the first class of harbors and the first division of the second class are well known. They consist in enclosing the waters to be protected by barriers called breakwaters upon which the force of storms shall be expended. The mouths of rivers which empty into the great lakes present certain peculiarities of importance in discussing projects of improvement.

Very few, if any, of the rivers emptying into the great lakes have sufficient volume of discharge to maintain a channel into the lake of sufficient width and depth to accommodate the wants of commerce. As a rule it is observed that except in times of freshets the volume of discharge is so small that the direction of the current at the mouth varies constantly with the rise and fall of the lake.

The lake surface is in a constant state of oscillation due to various causes which it is not the object of this paper to explain, of such extent and frequency as to give to the lower portions of the streams emptying into them the character of tidal rivers. These

oscillations are sometimes as great as three feet, but they are irregular as to extent and time of occurrence. They frequently take place several times a day causing an alternate ebb and flood current at the river mouth much in excess of the volume due to the discharge proper of the river. An oscillation of a foot is quite frequent. When we find, as is frequently the case, small lakes separated from the great lakes only by narrow strips of sand, the outlet of these lakes is maintained by this ebb and flow as on the seashore.

The improvement of these river mouths and inlets consists in widening and deepening the channel out to the deep water of the lake and in revetting the sides of the excavated channel. It is generally found that immediately inside of the mouth these streams have considerable depth but this is separated from the deep water of the lake by what is known as the bar. This is composed generally of sand or shingle. The existence of bars is sometimes ascribed to the deposit of sediment brought down by rivers but this is not the case with bars at the mouths of rivers emptying into the lakes as far as the writer's observations has extended.

The streams are generally free from sedimentary matter and when, as in some instances, they hold such matter in suspension it is not found on the bar but is diffused by the action of the waves. The idea of these bars can best be formed by imagining a new stream suddenly finding an outlet into the lake.

If we suppose a stream suddenly projected into the lake in a direction perpendicular to the coast when the latter is straight, it is evident that a direct channel will be excavated by the current. It is also evident that immediately after the current passes the line of the shore its force will be diminished as it meets the resistance of the water of the lake and spreads out so that the depth of the channel produced by it will diminish from the shore outward.

The consequence is that there will be a bank of sand or shingle extending from shore to shore in a semicircular form which is called the "bar."

This supposes the lake to be without storms or currents. The bar therefore is not caused by the river but is the material composing the natural bottom of the lake or sea which the river current in its diminished force is unable to disturb.

The depth and width of the channel over the bar depend on the strength of the current.

This bar, however, is subject to various modifications in form and extent by the action of the lake storms and currents, especially in the case of streams where the depth on the bar is small.

The effect of waves is to stir up the material on the bottom above a certain depth and this material being held temporarily in suspension is moved about by the current.

The southern portion of the west side of Lake Michigan is a good example of the effects of waves and currents.

The principal storms affecting this portion of the lake are from the North East. The waves constantly strike the shore at an angle of about 45 degrees and produce a strong littoral current in a southerly direction. The material on or near the shore out to a varying depth according to the height of the waves is stirred up and moved to the south. When it meets the mouth of a stream it is carried out and deposited on the north side of the channel so that the channel of the river is forced to the south.

This is found to be the case with all streams from Milwaukee southward and in many cases the mouths of streams are entirely barred up by the sand and shingle. The depth to which this drift motion occurs has not been determined but some years ago a vessel loaded with coal was wrecked some miles north of Racine, Wisconsin, and afterwards large quantities of this coal were found south of Racine and must have passed around the ends of the Harbor Piers which were in fourteen feet depth of water.

As stated above the discharge from these streams is small and insufficient to maintain a channel suited for navigation.

What natural channels do exist are crooked and changing by the action of storms. It is evident from the foregoing that if a channel were dredged through the bar it would speedily fill up unless some means were taken to prevent it.

This is done by revetting the banks of the channel and extending the revetment out to a depth of water beyond which the waves will not disturb the bottom.

This depth may be assumed at from eighteen to twenty-four feet in Lake Michigan for practical purposes. The class of harbor improvements which we are considering may be stated then to consist in making a channel of proper width and depth from the deep water of the great lake to the deep water of the river, lake or artificial basin inside and the construction of works for the maintainance of this channel.

This is generally the ultimate plan of these improvements but in their progress we may so place our works as to get the benefit of the river current in making a better channel especially during freshets.

During the past season (1872) there was only one stream on the west side of Lake Michigan and on Lake Superior where harbor improvements are in progress which has had a constant outward current at the mouth. This is the Menomonee River, Michigan, All the other streams have had a constant fluctuation of the direction of the current at their mouths.

In making the channel through the bar we are to consider *first*, its width and depth *second*, its direction *third*, the character of the works for its maintainance. Its

width should be, in the first place, sufficient to allow a free discharge of the river water during freshets and secondly to accommodate the necessities of commerce. In general our artificial channels are too narrow (about two hundred feet). This has partly resulted from motives of economy, (to reduce the amount of dredging) and upon the theory that the object of the piers was to confine the current of the river so as to scour out a channel between them. I think this theory is in general very fallacious very few of our rivers having sufficient discharge to scour out a channel two hundred feet wide and twelve feet deep as is shown by the fact of the channels filling up and in some cases absolutely closing up by the lake drift. In almost all cases dredging must be resorted to and kept up until the piers are extended to deep water.

The channel, when intended to afford a harbor of refuge during storms, should be not less than five hundred feet in width. This question however must be settled in each individual case. The direction given to the channel has generally been perpendicular to the shore and this is perhaps the best except in special cases. The works executed for protection of the channel are generally parellel piers extending from the shore at a distance apart equal to the width of the channel.

I regard this parallelism of the piers objectionable because it confines the waves entering the mouth of the harbor, whereas, if the distance between them increased toward the shore the sea would be reduced immediately after passing the heads of the piers. This arrangement of the piers has arisen from many considerations the principal one being, probably, that it enables a result to be accomplished in less time and at less expense than any other plan.

In designing a harbor plan of this class with ample means for its execution, the first thing done should be to fix the entrance to the harbor, i. e., the extremity of each pier, then connect these points with the shore on either side of the inlet to be improved, by curved or broken lines with their convexity outward.

The effect of these piers, extending from the shore, is to arrest the drift of sand and shingle and cause an accretion which necessitates the extension of the piers from time to time. This accretion is greatest on the side of the prevailing winds. Thus, at Milwaukee and southward the accretion is almost entirely on the north side while the shore on the south side is cut away; in the vicinity of Milwaukee or a little north the drift seems to be about equal on both sides, so that the material which is drifted southward by north-east storms is driven back by south east storms. This state of things is very favorable for the permanence of a harbor.

Proceeding further north we find the greatest accretion on the south side of the harbors, the drift caused by south-east storms exceeding that from north-east storms.

The piers and breakwaters in the lakes are constructed either of cribs of timber and iron filled with stone or of pile work. The details of these methods of construction are too well known to require description in this paper. It should be remarked, however, that they are in a certain sense temporary structures requiring frequent repair. The work under water, if put together so as to resist the forces to which it is subjected, may be considered permanent, as timber under fresh water will last indefinitely. Above water the timber work will last from ten to fifteen years when it must be renewed. This portion of the work, known as the "superstructure," may be replaced by masonry when substantial cribs are used.

This is one advantage which the crib pier possesses over the pile pier that has been adopted. A modification of the latter could be made by driving additional piles which would afford a support to a masonry superstructure by sawing off the piles at or below the water level after the portions above water had decayed. These two kinds of pier have their respective advantages. The pile pier adopted thus far consists of two rows of close piling filled in with brush or slabs, loaded with stone and surmounted by a superstructure of timber filled with stone. The rows of piles are tied together at the water surface by wooden ties connecting oak binders or wale pieces placed outside of the piles. This plan has the merit of economy but it is evident that if the ties give way the pressure of the filling will force the rows of piles apart and render repairs very troublesome. This however can be remedied by introducing ties of wood or iron below the water. The pile pier has the advantage of staying where it is placed if the bottom is favorable for this kind of work, which is more than can be said of the crib pier.

It is impossible, except under the most favorable circumstances, to make cribs remain in their places on the ordinary lake bottom without preparing a substantial foundation of loose stone. The bottom is generally clay overlaid with a stratum of sand of varying thickness. If a storm occurs after the crib is placed it has the effect of washing out the sand underneath the crib, causing the latter to tip over and, in some instances, to move it bodily from its place. In order to remedy this difficulty a trench is sometimes excavated to make a bed for the crib but this is an expensive and uncertain process.

The frequent recurrence of storms causes the trench to fill up, in whole or part, before the crib can be placed, causing either delays in the work or an uneven bottom for the crib to rest on. Another remedy which has been adopted is to make the bottom of the crib a grillage of timber with openings from two to three feet square. These openings are designed to admit stone through them to fill up the space below and thus form a foundation. This remedy is but partial and it has happened that severe gales occurring soon

after the crib was placed have so shaken it up as to cause all the stone filling to pass through and the consequent loss of the crib.

The first crib in the Chicago breakwater was placed at the north end of the work in twenty-four feet of water. The crib was fifty feet long, thirty feet wide and twenty-six feet high. Three months after it was placed during a heavy north-east storm the crib moved bodily to the north about twelve feet and to the east about one foot. This occurred in December, 1870, since that time the crib has not moved.

Crib piers, however, when well placed in good alignment and close together make a very satisfactory and substantial work. I think it would be an improvement on the present system if the centre part of the crib, dividing it lengthwise into three equal parts, were made with a close bottom and partitions put in to hold the stone over this portion. The object of the grillage would be secured by permitting the stone to pass through next to the sides while we would have a large immovable mass in the centre sufficient of itself to hold the crib under ordinary circumstances. In practice stone foundations are formed by holding the crib up two or three feet above the bottom and throwing in small stone which find their way through the grillage bottom and thus form a foundation. Stone is afterwards thrown in outside of the cribs to prevent undermining. The adoption of these modes of construction has grown out of the necessities of the case, mainly the want of means to construct more durable and substantial works. The rapid increase of the lake commerce is such that there is not time for the construction of such elaborate works as we find in the old world.

The Plymouth breakwater in England, recently finished, was commenced before the city of Chicago was thought of and was built at an enormous cost.

The system adopted on the great lakes could be as well adopted on the seashore but much more expensive works would be required. The use of timber which lasts indefinitely in fresh water would have to be dispensed with. The piers would require to be constructed of masonry or loose stone. The plan adopted in Holland of using fascine work has advantages of economy and should be tried on our great lakes. This plan is described in Professional Papers, Corps of Engineers, No. 22, by Gen. Barnard.

There has been much discussion as to the form to be given to the cross section of breakwaters which are exposed to the force of waves. There are those who advocate the long slope and others who advocate a vertical face to the exposed side. Some engineers have given a curved form to the exterior face. There are examples of all these forms. The discussion of their respective merits involves the theory of waves and the manner in which their force is exerted. The advocates of the vertical wall argue that in deep water where the waves do not break they have simply an oscillatory motion,

nearly vertical, and, consequently, the particles of water will move parallel to the face of the wall and exert little if any pressure against it except the hydrostatic pressure due to the height of the wave, whereas, in the case of a sloping wall this oscillating motion is converted into a motion of translation, as on a beach, and the water is propelled forward with greater or less velocity, depending on the height of the wave. From which it follows that in water so deep that the wave does not break, an upright wall is the best form, but in cases where the water breaks before reaching the pier, an inclined slope affords the least resistance to the horizontal motion of the water and allows it to rise gradually until the force developed has expended itself in overcoming the gravity of the water.

It seems to me in the case of a harbor formed in the open sea so as to enclose a portion of it and cause smooth water, when without the protecting works there would be a heavy sea and tremendous surf on shore, that these works must be exposed to precisely the same force that formerly produced the motion inside, in other words, that the force to be resisted is that formerly resisted by the shore.

According to the upright theory all that would be necessary for a breakwater in deep water would be a vertical wall of sufficient weight to withstand the hydrostatic pressure of a column of water due to the greatest height of the waves or the difference of level on the two sides of the wall.

It seems to be contended that a vertical wall has no resistance to overcome, but if you put a sloping wall a tremendous force is developed, and that there is some mysterious power in a mathematical figure by which power is suddenly created. This seems absurd, yet it is a fair conclusion from the statements of many of the advocates of a vertical wall.

The fact is that a certain resistance must be overcome which is entirely independent of the form of cross section and the question is simply as to the best disposition of the materials at our disposal to afford this resistance. The best form mathematically speaking, to be given to a breakwater is a long slope or wedge toward the sea, and this form requires the least strength as it has only to resist a small component of the wave force.

Breakwaters however of this form have always been composed of loose materials easily moved and in order to get this form enormous quantities of material have been used to furnish a base while in upright breakwaters masonry has been employed so that the shock is sustained by the entire mass of the work. If sloping breakwaters were constructed in the same manner, we should not hear of the injuries which they have sustained. The objection to sloping breakwaters is their mode of construction and cost, not their form. For these reasons masonry walls are employed in many instances. It is important that they have a good foundation and be thoroughly constructed. In all cases

where these walls have been successful, great care has been taken with the foundation and considerable thickness given to the work so as to obtain a mass sufficient to resist the force of the waves.

When large cribs of timber filled with stone are used, it is mainly important that the foundation on which they are placed be prepared so as not to undermine. Owing to the great mass which can be given to the cribs the question of cross section becomes less important. The form of breakwater which seems to be most suitable in the general case, consists of a wall, the sides of which have a slight batter, placed upon a foundation of rubble stone. The top of this foundation should be placed at a depth where the materials composing it are not disturbed by the action of waves. An example of this form is found in the piers of the harbor at the mouth of the North Sea Canal of Holland. The worst form of breakwater is the long slope brought up to just above the water level and then surmounted by a parapet. The latter is then placed so as to receive in a limited space the almost entire wave force.

THE ORBIT

OF

THE BINARY STAR STRUVE 1757.

READ BEFORE THE ESSAYONS CLUB OF THE CORPS OF ENGINEERS,

DECEMBER 16, 1872;

FROM

LIEUT. EDWARD S. HOLDEN,
CORPS OF ENGINEERS.

NO. XXVI. PRINTED PAPERS.

Printed on the Battalion Press.
Corpl. Carmichael & Pvt. Redfield, Printers.

ON THE ORBIT OF THE BINARY STAR STRUVE 1757.

A paper read before the "ESSAYONS CLUB" of the Corps of Engineers, on December 16, 1872, from 2nd Lieut. Edward S. Holden, Corps of Engineers.

The mean AR of this star is 13 h. 26 m. 38 s. and its mean Declination is 0° 27′ N, both co-ordinates being for 1850.0. The magnitude of the larger is $7\frac{1}{2}$ to 8, and of the smaller 8 to 9, according to various estimates. No signs of variability in these stars have been noted. The Rev. W. R. Dawes has given their colors as "A yellow, B paler yellow", and again as "both white", in *Mon. Not. R. A. S. vol.* 26.

An examination of the methods of M. Savary (*Conn. des Tems for* 1830, *p.* 56) of M. Yvon Villarceau (*Mélanges Math. et Astr. tome* 1*er p.* 72*me.*) and of Sir J. F. W. Herschel (*Proc. London Astr. Soc. vol.* 5 *p.* 171.) has led me to prefer for ordinary cases, the latter method. In the cases of stars like 42 *Comae Berenices*, where the equality of the components almost completely invalidates the measures of angle of position it is necessary to have recourse to the measured distances. Ordinarily, however, the use of the distances introduces errors which are much greater in their effects than any made by the roughest approximative methods of calculation.

If distances are used at all it is much better to use those of a single observer since the *relative* shape of the orbit is thus preserved. The most cursory examination of published observations of distances will convince one of this fact, as enormous discrepancies (for their effects on calculation of orbits) exist between simultaneous distances of various observers.

I have been led to believe that in spite of the extremely long period of this star, accordant results might be expected from its observations, which belief my results seem to justify.

The observations of position and distance which I have used are as below and are extracted from the appendix to Dawes' Catalogue of Double Stars.

No.	Date.	Observed Position Angle.	Obs'd. Distance.	Authority.
		°	″	
1	1825.37	10.0	1.600	Struve, 1 night
2	29.82	19.5	1.445	Struve, 2 "
3	33.38	23.9	1.540	Struve, 2 "
4	35.37.	25.50	1.667	Struve, 3 "
5	36.42	29.45	1.645	Struve, 2 "
6	38.48	31.00	1.700	Smyth.
7	41.38	36.03	1.747	Mädler, 4 nights
8	42.39	37.42	1.678	Dawes, 2 "
9	42.52	37.90	1.700	Smyth.
10	43.45	38.82		Dawes.
11	45.88	40.81	2.026	Mädler.
12	52.38	51.70	2.000	Smyth.
13	53.09	52.25	2.056	Mädler, 3 nights
14	54.37	50.18	2.162	Mädler, 5 "

From the interpolating curve constructed from the above observations, and from the apparent ellipse constructed by their aid, I deduce the following elements of the apparent orbit:

Semi-axis major	=6″.466	Position of semi-axis major	349°.
Minor axis	2″.639	Minimum distance	0″.731
Position of minimum distance	290°.	Motion direct.	

A comparison of the observed and interpolated angles of position and distances gives us the following:

No.	Obs. Angle.	Int. Angle.	Int.—Obs.	Obs'd. Dist.	Int'd. Dist.	Int.—Obs.
	°	°	°	″	″	″
1	10.0	10.0		1.600	1.421	−0.179
2	19.5	19.8	+0.3	1.445	1.675	+0.230
3	23.9	24.4	+0.5	1.540	1.634	+0.094
4	25.5	27.6	+1.1	1.667	1.685	+0.018
5	29.45	29.0	−0.45	1.645	1.695	+0.050
6	31.00	32.2	+1.2	1.700	1.726	+0.026
7	36.03	36.3	+0.27	1.747	1.786	+0.039
8	37.42	37.4	−0.02	1.678	1.807	+0.129
9	37.90	37.9		1.700	1.809	+0.108
10	38.82					
11	40.81	42.3	+1.5	2.026	1.857	−0.169
12	51.70	50.2	−1.5	2.000	1.939	−0.061
13	52.25	51.2	−1.05	2.056	1.964	−0.092
14	50.18	52.6	+2.42	2.162	1.969	−0.193
			$\sigma = +1°.85$			$\sigma = -0″.001$

By an examination of the above table it is evident that the interpolated and observed distances agree remarkably well; the sum of the + corrections being 0″.694, and of the — corrections being 0″.695. The discrepancy in the angles of position has caused me much dissatisfaction, but after many trials it has been decided to allow the interpolating curve to remain unchanged for the following reason: the last observation of position angle, that of Mädler, although the mean of five nights' observations, is plainly wrong, being too small. The law of increase of position angle (with the time) could not change at this point unless some critical point of the apparent ellipse was then reached. The subsequent first computation shows that no such point was here reached. Hence we must conclude Mädler's observation too small.

The next question is "How much too small is it?" and to answer this let us take the last three observations of Mädler Nos. 11, 13, and 14 and write them as below with their corresponding interpolated angles θ'. They are

	θ	θ'
No. 11	40.81	42.3 .
No. 13	52.25	51.2 .
No. 14	50.18	52.6 .

We only compare Mädler's observations among themselves because our method would not apply to those of various observers.

We may presume, now, the interpolating curve to be *relatively* correct and we may correct the value of observation No 14 by the proportion

51°.2—42°.3 : 52°.6—51°.2 :: 52°.25—40°.81 : the correction to No. 13.

We find this to be 1°.99 whence the sum of the column of interpolated — observed position angles will be—0°.14 a much closer accordance than could have been expected. We may then assume the interpolated values as *absolutely* correct. Proceeding onward from this point according to the method of Sir John Herschel we find for the elements of the orbit of Struve 1757:

Semi-major axis	: 10″21
Position angle of perihelion	: 340°.7
Eccentricity	: 0.7937
Date of perihelion passage	: 1815.04 A. D.
Mean motion	: +0°.24
Inclination	: 58°.03′
Position of Node	: 10°.59′
Periodic time	: 1490.8 years.

These elements are of their nature but approximations but I believe them to be as nearly accurate as most of the concluded elements of Binaries. This particular Binary is of no peculiar note but has been selected simply from a belief that it would give good results, and from a knowledge that no work of this nature is without some value.

Note.—All observations of this star which I could collect have been used but I learn from Prof. Newton of Yale College that other observations, later ones, exist. I have been so far unable to find these in printed observations, but intend to recompute the orbit when a sufficient number shall have been procured.

NOTES

ON

MODERN EXPLOSIVES.

READ BEFORE THE ESSAYONS CLUB OF THE CORPS OF ENGINEERS,

JUNE 2, 1873;

BY

BVT. BRIG. GEN. HENRY L. ABBOT,
MAJOR OF ENGINEERS.

NO. XXVII. PRINTED PAPERS.

Printed on the Battalion Press.
Corpl. Carmichael & Pvt. Redfield, Printers.

ERRATA.

Insert on page 2 the following paragraph next after that ending with "exterior :"

By replacing a part of the carbon with uncarbonized peat, Mr. Oliver now manufactures a variety of gunpowder which, when well rammed, is claimed to give a higher initial velocity with a less recoil and less smoke than the ordinary grades. This advantage is attributed to slow burning.

NOTES ON EXPLOSIVES.

A paper read before the "ESSAYONS CLUB" of the Corps of Engineers, on June 2, 1873, by Bvt. Brig. Gen. Henry L. Abbot, Major Corps of Engineers.

Under the head of explosives, (*ex* and *plaudo*, a burst of sound,) will be considered the compounds practically available in war, in mining, and in general use for the sudden developement of immense force. They comprise gunpowder; guncotton; Schultze powder; nitro-glycerine, with its compounds known as dynamite, or giant powder, glyoxiline, lithofracteur, and dualin; admixtures of potassium chlorate, with readily oxidizable substances; and the picrate compounds. The various fulminates of mercury, silver, copper, etc., although very powerful agents, are too liable to accidental explosion for practical use, except in very small quantities, as primings for percussion-caps, fuses, etc., and they are therefore excluded from consideration.

Gunpowder, which was first employed in war about the year 1350, is the oldest and most generally useful of these agents. It is a mechanical mixture of potassium-nitrate, carbon, and sulphur, in proportions usually varying but little from 75, 13, and 12 respectively. Purity is essential to excellence. The manipulations of manufacture consist, in general terms, in very finely pulverizing the ingredients; thoroughly incorporating them; compressing them into a cake; granulating it; separating the different sizes of grain by sieves; glazing; drying; and finally removing all dust by the use of fine sieves.

In the storage of gunpowder, special precautions against fire and moisture are needed. A spark, friction between hard bodies, or a temperature raised suddenly to 572 degrees Fahrenheit, determine an explosion; while slight moisture, which may readily be absorbed from damp air, produces caking and deterioration. A wetting is permanently destructive to the compound. Frost produces no injurious effects, either temporary or permanent.

Being a simple mechanical mixture, the properties of gunpowder may readily be varied to suit the requirements of a quick burning, or a slow burning explosive. Its

expansive power is due to two distinct causes—the sudden transformation from a solid to a gaseous form of vastly greater volume, and the heat developed by the chemical change, which induces enormous tension. It is apparent, therefore, that a variation in the relative proportions and condition of the ingredients, by changing the chemical products of the explosion, must affect the expansive force; and also that a similar result may be obtained by mechanical means directed to modifying the duration of the time required for combustion.

It is to a skillful application of the last method, that the recent improvements in gunpowder designed for heavy ordnance are due. General Rodman, of the United States Army, inaugurated a series of experiments directed to this end, in 1856, and from the results of his labors this country was provided in advance of European nations, with an explosive suited to modern cannon. His mammoth and perforated cake powders—the former consisting of large irregular grains, tested by two standard sieves of $\frac{6}{10}$ and $\frac{9}{10}$ inches respectively, and the latter of hexagonal or cylindrical cakes, perforated by holes—have been copied in the English pebble and pellet, and the Russian prismatic powders; by the aid of which the recent improvements in their artillery have been rendered possible. Pebble powder is simply pressed cake, broken into large irregular pieces and glazed. Pellet powder consists of mealed powder compressed into small blocks, of regular and sometimes indented forms, and of dimensions varying for different calibres. Prismatic powder consists of mealed powder compressed into flat perforated cakes of hexagonal form, about an inch thick and an inch and a half on the longest diameter. This subject is still undergoing investigation; the facts having been developed that the time of burning, and hence the strain upon the gun for a given initial velocity in the projectile, may be modified by varying the size and form of the grains, their density and hardness, and the mechanical condition of the exterior.

The maximum pressure of exploded gunpowder, unrelieved by expansion, has been investigated by various parties, whose results range from 7 tons to 662 tons to the square inch—the latest authorities indicating about 40 tons.

The difficulty of obtaining saltpetre in large quantities, and hence its cost, has induced many attempts to replace it by other nitrates, such as those of sodium, lead, and barium; but although good blasting powders have been thus prepared, none suited to propelling purposes have been obtained.

Guncotton. In 1832 Braconnet discovered that by dissolving starch in nitric acid, and adding water, a white explosive substance was precipitated, to which the name xyloidin was given. Shortly after, Pelouse obtained a similar compound by treating paper, or cotton or linen fabrics, with nitric acid; and named it pyroxilin. These were

the precursors of guncotton, which was discovered by Schönbein in 1846; and at once excited much attention as a possible substitute for gunpowder. Adverse official reports, however, were soon made in France, the United States, Germany, England, and Austria, and the explosive fell into general disfavor on account of its liability to spontaneous explosion, its corroding residua, and its excessively violent and irregular character, all of which unfitted it for most military uses. Baron von Lenk, a member of the Austrian commission, was not so readily discouraged. He continued a series of experiments for several years, which ultimately led to so great improvements in manufacture, that in 1853 he was able to construct a successful twelve pounder battery employing guncotton. This led to its temporary introduction into the Austrian military service, and again attracted the attention of foreign nations to the new explosive.

Baron von Lenk's system consisted in cleansing the long-staple variety of raw cotton in an alkaline wash, followed by one in pure water; thoroughly drying it; steeping it for forty-eight hours in a cold mixture of strong nitric and sulphuric acids—one part of former to three parts of latter by weight; freeing the resulting tri-nitro-cellulose from the acids by a centrifugal machine, by thorough rinsing, and finally by the action of running water for a period of six or eight weeks, alternated with a boiling potash bath and hand washing; air-drying it; rinsing it in a hot solution of potassium silicate to retard the rapidity of combustion; and, lastly, again washing and thoroughly drying it. He partially regulated the suddenness of explosion by twisting the guncotton into ropes, or weaving it into cloth to secure a more uniform density. Musket cartridges were formed by wrapping the thread around wooden plugs, to prevent unequal ramming. An admixture of a certain proportion of ordinary cotton was also employed to reduce the violence of action.

In 1863 Mr. Abel, as a member of a committee appointed by the British War Office, undertook an experimental investigation into the merits of this system; and succeeded in materially improving it. Instead of the costly long staple cotton, he employs ordinary cotton waste, which is treated with the mixed acids, one part of nitric to three of sulphuric by weight, without any preliminary process except careful drying. It is then rinsed in a large volume of water, and dried by a centrifugal apparatus, three or four times. Next, it is placed in a pulping engine, like those commonly used in the manufacture of paper, and reduced to a state of fine subdivision. It is then transferred, in quantities of at least 10 cwt., to a poaching engine, where it is beaten for about forty-eight hours until it remains uniformly suspended in a large volume of warm water, continually renewed, and finally rendered slightly alkaline. It is then dried in a centrifugal machine, and moulded into disks of the desired form and dimensions, which receive

a pressure ranging from 4 to 6 tons per square inch. Up to this point the guncotton has been in a damp, and consequently entirely safe state; and if desired it may be so stored for an indefinite period of time, without losing its peculiar properties. To prepare it for use, it is dried upon hot plates, freely open on every side to the air. This system of manufacture is the best now known, and yields a product so uniform and safe as to be employed in England almost to the exclusion of all the other modern explosives.

In appearance, ~~Able~~ guncotton consists of regular cylinders of dimensions varying with the use proposed. It is white in color, hard to the touch, and sinks readily in water. Ignited, unconfined, by a flame, it burns with a strong blaze. Fired by a detonating fuse, or raised to a temperature of about 340° Fahrenheit in a strong case, it explodes with great violence—a single ounce being sufficient to indent a plate of iron, or disrupt a thin slab of stone upon which it is loosely laid. The character of the detonation varies with the fulminate employed, being most sudden with fulminating mercury. Even in a damp state—containing twenty per cent of moisture—it may be exploded without much loss of power, by a disk of dry guncotton in contact. It is believed, upon good grounds, to be free from danger of spontaneous explosion. The English government has adopted it, as the explosive best suited to submarine warfare, and has accumulated large quantities in store.

Guncotton produces little smoke, and leaves a very small residuum of solid matter, the chief products of combustion being carbonic oxide, carbonic acid, water, and nitrogen. It is unalterable in water, no matter how long submerged. It contains about 2 per cent of moisture in its normal condition, and even when exposed to ordinary damp air, it absorbs but little more, a property which gives it a great advantage over gunpowder. Chemically, the purest guncotton may be regarded as cellulose, in which three atoms of hydrogen are replaced by three molecules of peroxide of nitrogen. Thus constituted, it is insoluble in mixtures of ether and alcohol. If, however, great care has not been observed in the manufacture, less simple compounds are formed, which may readily be dissolved in these mixtures—forming collodion, so much used in photography and the arts.

Quite recently, Punshon has succeeded in so reducing the quickness of action of guncotton by mixing with it nitre and crystals of cane sugar, as to make it well suited for use in small arms. Indeed, the present subject for investigation in connection with guncotton, appears to be the admixture with it of some oxidizing agent, such as potassium or sodium nitrate; experiments have indicated that an increase of power may thus be gained.

Schultze powder. The conversion of lignin, or wood-fibre into an explosive similar to guncotton, was attempted soon after the discovery of that compound—especially by

Captain Schultze, acting for the Prussian government. His method consisted in soaking the wood—preferably alder—in water, to give it toughness; cutting it by fine saws into a kind of cross-grained veneering; and subsequently punching it into small cubes of which the size varied with the use for which the powder was designed. The grains thus produced were boiled in a solution of soda, and afterwards alternately exposed to steam and washed in a solution of chlorine to free them from resins, etc. They were next treated for several hours with mixed nitric and sulphuric acids, kept cool by constant stirring, and afterwards were thoroughly washed and dried. In this state, the powder is but slightly explosive, and it may be kept in store indefinitely. For use, the grains must be submerged for about twenty minutes in a solution of nitrate of potassa and baryta, and then carefully dried and sifted. The necessary oxygen having been now supplied, the powder has a high explosive power. It burns with but little solid residuum or smoke, and is said to be both cheaper and stronger than common gunpowder, weight for weight. It however readily attracts moisture, is liable to form dust by attrition, and is more bulky than gunpowder, in the proportion of 3 to 1.

Nitro-glycerine, or glonoin oil, was discovered in 1847 by Ascagne Sobrero, but remained unapplied to practical uses until 1864, when Alfred Nobel, a Swedish engineer, began to develope its industrial value. Since then it has been largely employed upon the continent of Europe, and in America. It is prepared by the action of a mixture of concentrated nitric and sulphuric acids, upon glycerine introduced drop by drop. At ordinary temperatures, it is an oily liquid usually colorless if made from good glycerine, but sometimes discolored by causes not well understood. It has no odor, and is of a sweet and slightly pungent taste. It is highly poisonous, even short contact with the skin being sufficient to produce severe headache. Its specific gravity is 1.6. When first made, it has a milky appearance which ultimately disappears. Nitro-glycerine incompletely freed from the acids, undergoes spontaneous decomposition, is dangerous to handle, and ultimately may lose its explosive properties. When pure it congeals at from 40° to 45° Fahrenheit, and is then nearly or quite incapable of explosion. At 212° Fahrenheit, it begins to decompose; at 365° Fahrenheit, it throws off yellow or reddish fumes; at 423° Fahrenheit, it deflagrates violently. When uncongealed, nitro-glycerine may readily be exploded by concussion—which renders it quite unfit for transportation in that state. In store, it should be kept in a cool place, under pure water, in open vessels, and, if practicable, in a frozen condition. For use, it should be thawed very gradually, by placing the can in warm water raised to a temperature not exceeding blood heat. Any leakage should be carefully avoided at all times, and emptied cans should be destroyed. Flame applied to

small quantities of nitro-glycerine causes it to burn with difficulty, like ordinary oil, but a fulminate exploded in contact with it, produces a tremendous detonation. To develope its full effect, fulminating mercury, in quantities not less than 15 troy grains, and confined in a strong copper capsule, is recommended. Its advantages as an explosive consist in its instantaneous development of force—due to the fact that, pound for pound, it produces at least three and a half times as much gas, and twice as much heat as gunpowder; its high specific gravity, which permits the use of small drill holes; its admitting of water, or loose clay, or even air tamping; and finally, the facility with which it can be made upon the spot for immediate use. Its disadvantages are the severe headaches it causes to those not habituated to its use, its liability to spontaneous explosion, the dangers sure to attend its careless handling, and, especially for military uses, its unfitness for being kept long on hand, unless prepared and treated with a degree of care not readily to be secured. To these may be added the fact that its rate of explosion is not under control, which restricts its economical use to blasting in hard rock, or under water. In soft rock or clay, its power at equal cost is inferior to that of common gunpowder, because its action is akin to a sudden blow, rather than to a continued push.

Dynamite, called in the United States giant powder, was invented in 1866–67, by Nobel; it consists of nitro-glycerine absorbed by some porous inert solid. The percentage of the former is of course limited by the capacity of the absorbent. The best material is a silicious infusorial earth found in Hanover, and known as kieselguhr. It is when dried a white impalpable powder, showing under the microscope a cellular structure. It will absorb and safely retain three times its weight of nitro-glycerine. Many experiments were made in Paris, during the late siege, to discover the most suitable substitute there available. Finally, a residue from the gas works was adopted, which would take up and retain a little more than its own weight of nitro-glycerine.

Dynamite made from kieselguhr has the appearance and consistence of heavy brown sugar. It possesses most of the virtues of the parent nitro-glycerine, with some peculiar to itself; of which the chief are, exemption from liability to spontaneous explosion, and to detonation from moderate shocks, both of which result from the exceedingly fine granulation of the nitro-glycerine. It has been very largely used in this country, especially in California; and these important advantages are now generally admitted. Dynamite possesses another decided advantage over nitro-glycerine. If kept in the state of loose powder without compression into cartridges, it may be exposed to any natural temperature without losing its explosive properties, when subjected to the action of the ordinary primer charged with 15 grains of fulminating mercury—and this too without becoming more sensitive to ordinary shocks and handling. In the form of

compressed cartridges, it is as inexplosive when thoroughly frozen, as nitro-glycerine itself. Saturated with water, it loses only a very small percentage of its explosive power, but requires a primer much more powerful than those ordinarily used. Ignited by a flame, and unconfined, it burns quietly without detonation. Experiment indicates that its explosive force is not quite so instantaneous as that of pure nitro-glycerine; hence, in certain kinds of resisting media, where a sustained pressure is required, the mechanical work performed by three-quarters of a pound of nitro-glycerine in the form of dynamite, may largely exceed that produced by a full pound of the unabsorbed material. This apparent paradox actually occurs in submarine mines, usually called torpedoes. For rock blasting, dynamite should be pressed firmly home and tamped with sand.

Dynamite possesses another merit. By combining its ingredients in judicious percentages, a certain control can be exerted over the quickness of its action, and a classification similar to that of the different grades of gunpowder, but much more restricted in range, may be made.

Various have been the attempts to improve upon dynamite by replacing its inert base with different explosive materials. Of such compounds, glyoxiline, lithofracteur, and dualin are the best known; but none of them are believed to be improvements for rock blasting, chiefly for the reason that the bulk is increased in a higher ratio than the power, and hence, as the cost is largely dependent upon the size of the drill-holes, no real economic gain is made.

Glyoxiline was invented by Abel shortly after the introduction of dynamite. It consists of a mixture of guncotton pulp and potassium nitrate, saturated with nitro-glycerine; and was made both in a granular and a cake form. It proved to be less troublesome in handling, owing to the granules being coated with an impermeable material which reduced the tendency to produce headache; but it was never largely introduced into practical use.

Lithofracteur was devised about the same time, by Prof. Engels of Cologne. Its precise composition is not made public, further than that it consists of 525 parts of nitro-glycerine, 225 parts of silica, and 250 parts of mineral bodies; and analyses of different samples have exhibited varying results. One authority (Trauzl) reports 52 parts of nitro-glycerine, 30 parts of kieselguhr, 12 parts of coal, 4 parts of sodium nitrate, and 2 parts of sulphur. Others place the proportion of sodium nitrate as high as 25 per cent; others add guncotton. Lithofracteur is a pasty substance of dark color. Like the other compounds of nitro-glycerine, it burns quietly when ignited by a flame, and explodes violently when fired by a detonating fuse. Water dissolves the sodium nitrate, and thus sets free a cer-

tain part of the nitro-glycerine—of course a decided disadvantage. The compound exhibits explosive properties similar to dynamite, and offers equal security against concussion. Its use heretofore has been restricted chiefly to Germany and Belgium, although it has been experimentally tried in England, and was employed by the Germans in the late war with France.

Dualin was invented by Dittmar shortly after dynamite, and its use has been chiefly restricted to Germany and the United States. The patent describes it as consisting of "cellulose, nitro-cellulose, nitro-starch, nitro-mannite, and nitro-glycerine mixed in different combinations, depending on the degree of strength which it is desired the powder should possess, in adapting its use to various purposes." A sample supplied by the inventor for trial at the Hoosac Tunnel, was found by analysis to consist of 60 per cent of nitro-glycerine, and 40 per cent of washed sawdust, not treated with nitric and sulphuric acids. Tranzl reports it as consisting of 50 parts of nitro-glycerine, 30 parts of fine saw-dust, and 20 parts of potassium nitrate. The best variety now manufactured, is believed to be cellulose derived from poplar pulp, treated with nitric and sulphuric acids, and saturated with nitro-glycerine.

Having a less specific gravity than dynamite, dualin is slightly inferior to it, bulk for bulk, in explosive energy. When thoroughly soaked in water, it can only be exploded by a very violent detonation, much exceeding that of the ordinary fuse, and even then it loses more than half its power. It congeals at about 45° Fahrenheit, and in this state readily explodes, becoming so sensitive to friction as to make it dangerous to tamp in cold weather. In other respects its properties resemble those of dynamite.

The Chlorates. The violent action of potassium chlorate upon readily oxidizable substances, has given rise to many attempts to employ it in the preparation of substitutes for gunpowder. Under the names of white gunpowder, and German gunpowder, a mixture of this salt with potassium ferro and ferri-cyanide and sugar, has long been known. Mixed with nut-galls, resins, and other vegetable substances, it has been repeatedly introduced to temporary use as Horsley's powder, Ehrhardt's powder, etc. The form best known in this country consists of potassium chlorate, potassium nitrate and crude gamboge, which under the name of Oriental powder, or safety compound of the Oriental Powder Company, was at one time considerably employed in the oil-wells of Pennsylvania and for other blasting purposes. Its dangerous sensibility to friction, and the consolidating effect of heat upon the gum, have prevented its general use. With some of these chlorate compounds, sulphur enters as an ingredient; which intensifies the chief objection against them—their liability to explode from slight friction or percussion. As a class, they have many times the explosive ~~energy~~ of gunpowder, but are also more dangerous

to handle. For special purposes, they are extremely useful—for instance a mixture of potassium chlorate and sulphur, formed into a paste, and dried to fit small cartridge cases of lead, has been found to be terribly effective as a charge for explosive bullets. They may be fired with safety from a musket, but explode with great violence, even in penetrating flesh.

The Picrates. Picric acid was discovered in 1788 by Haussman, while treating indigo with concentrated nitric acid. Within a few years chemists have derived it from other substances, especially from carbolic acid. It has been called amer d' indigo, amer de Welter, carbo-nitric acid, nitro-picric acid, carbazotic acid, and tri-nitro-carbolic acid. It is a crystalline body, of a brilliant golden yellow, and very bitter to the taste; it is largely used as a dye. When heated to 600 Fahrenheit, it detonates with violence.

The salts obtained by treating many of the bases with picric acid, possess its characteristic properties; that best known is the potassium picrate. This forms golden crystals, having a metallic reflection. Insoluable in alcohol, and but slightly soluable in water, it detonates violently at 600 degrees Fahrenheit. Its action is akin to that of the fulminates in suddenness; and to regulate this property, Designolle has mixed it with charcoal and potassium nitrate; thus forming a compound similar to, but more powerful than ordinary gunpowder. To obtain the maximum explosive energy, he employs equal parts of potassium nitrate and potassium picrate. For use in rifles, from 12 to 20 per cent of potassium picrate is used, with a small amount of charcoal. For cannon, only from 8 to 12 per cent of potassium picrate is employed. Under the name of *poudre Designolle*, this compound has been considerably manufactured in France for military purposes, both for large guns, and for torpedoes.

Brugiere powder consists of an admixture of ammonium picrate and saltpetre. It is comparatively a slow powder, less liable to attract moisture than ordinary gunpowder, and yielding but little smoke. In England, Abel has experimented with a similar compound, to which he has given the name of picric powder, and which he considers especially suited for use in shells; because, although little liable to explode from concussion or friction—the great objection to the potassium picrate compounds—its effects when strongly confined, are more violent than those of gunpowder.

DYNAMITE WORKS

OF THE

ATLANTIC GIANT POWDER CO.

READ BEFORE THE ESSAYONS CLUB OF THE CORPS OF ENGINEERS,

FEBRUARY 17, 1874;

BY

CAPT. ALEXANDER MACKENZIE,
CORPS OF ENGINEERS.

NO. XXVIII. PRINTED PAPERS.

Printed on the Battalion Press.
Corpl. Carmichael & Pvt. Redfield, Printers.

NOTE.

This paper was prepared in compliance with instructions issued from the Headquarters of the Battalion of Engineers—under approval and direction of the Hon. Secretary of War and the Chief of Engineers—directing each officer of the Battalion to visit and examine, during the winter suspension of drills, some specified public work or manufacturing establishment. By request it was read before the Club; and being considered to contain information of interest to Engineer officers, it was ordered to be printed.

This note is prefixed by a vote of the Club, in order to explain the peculiar character, and necessarily limited scope of the paper.

DYNAMITE WORKS OF THE ATLANTIC GIANT POWDER COMPANY.

A paper read before the "ESSAYONS CLUB" of the Corps of Engineers, on February 17, 1874, by Captain Alexander Mackenzie, Corps of Engineers.

The Atlantic Giant Powder Company manufacture what is known in Europe and this country as Dynamite. When establishing their works in California they gave the name of Giant Powder to their explosive; but the term Dynamite is much better known, and now used even by the Company themselves, in preference to Giant Powder.

GENERAL ARRANGEMENT OF THE WORKS.

The works of the Atlantic Giant Powder Company are located in New Jersey about one mile from Drakesville, a small station on the Morris and Essex Railroad, and fifty miles from New York City. Hid away in a valley of the mining hills, these works, though convenient to two railroads and a canal, are as secluded as though nature had intended the spot for their especial use.

To reach the works from the depot a main road is followed for about three-quarters of a mile. Here a sign-board labelled "Atlantic Giant Powder Works—No Admission," marks a by-road through the hills. Following this road for one quarter of a mile you suddenly come upon the valley, above referred to, and scattered through it, you see the works of the Company. Even after coming as far as this, a stranger would hardly imagine himself on dangerous ground, were it not for the numerous signs labelled "No Admission" and "No Smoking." Most of the buildings are old and small, and with the exception of an occasional man or animal, the general effect is that of a deserted farm.

The Company own about two hundred acres of land. Their works occupy but a small part of this ground. The remainder is divided into orchards, groves, meadows and gardens for the employees. The whole must present in summer a very beautiful appearance.

The hills forming this wide valley abound in iron ore. Many mines are in active operation and furnish a convenient market for quantities of the dynamite. A few

villages are scattered through the valley within sight of the works, but they are all at a sufficient distance to prevent any fear, on their part, of an unusual disturbance. A few farm-houses are found near enough, to give their owners or occupants an idea of what is going on, but all these people have been employed by the Company, hauling acids from, or powder to, the depot.

The accompanying sketch (Fig. 1) will give a general idea of the arrangement of the works. Approaching by the road (*a*) you pass between the acid house (*b*) and cooling house (*c*), both small sheds; the former is used for storing the nitric and sulphuric acids as they come from the chemical works, and the latter is used for cooling and storing the acids after they are mixed.

The nitro-glycerine house, situated at *d*, is a light frame structure built on the side of the hill, in four steps. On the upper step the acids and glycerine are received, ready for mixing; on the next, are the nitro-glycerine machines for making the explosive; on the third, are immense tanks for washing; and on the fourth or last, are tanks and bowls for final washing, neutralizing the acids and making the powder. The floor of this room is kept perfectly clean and the temperature is kept even. All the water is brought from a spring back in the hills, and having a fall of sixty feet, drives itself through the building with considerable force. The existence of this spring was one of the principal reasons for establishing the works at Drakesville.

Passing on some distance we come to the packing house (*e*); here in one room the paper cases are made and oiled, and in another room the cases are filled and the cartridges are packed. About four men are employed at this work.

At *f* are seen some old sheds used for storing Kieselguhr and other material. The magazines are at *g*: the one is an old, dry stone out-house seldom used; the other is a new frame building capable of storing at least twenty-five tons of powder, though it seldom contains more than ten thousand pounds. This magazine is under the hill and surrounded by trees; it will never attain a very high temperature in summer, and the cold of the winter does not injure the powder.

The building *h*, is a mill for grinding and mixing guhr for both No. 1 and No. 2 dynamite; it also contains a vacuum pan for boiling the glycerine, and a bench for making exploders. A small compact engine runs the rollers and iron cylinders used for crushing the various ingredients before mixing.

Opposite the mill are several raised platforms, and a shed for drying the Kieselguhr. During the winter this operation is performed in the mill.

Further on at *i* is the boarding-house for the hands. About twenty men are employed

throughout the entire works. The making of the nitro-glycerine is under the charge of Mr. Johnson, a Norwegian; he has the entire control of everything in the nitro-glycerine house. The rest of the works are under the charge of Mr. Charles Varney.

The ease and rapidity, together with the carefulness with which each man does his work, inspires great confidence in a looker-on; and it would seem impossible for an accident to occur, where every man knows so well when and how to do his duty. Chinamen were sent from San Francisco when the works were first established, but they were soon sent back, and their places supplied with more intelligent workmen.

MATERIALS USED IN MAKING DYNAMITE.

Kieselguhr—for No. 1 dynamite is imported from Germany in bags or barrels. It costs but little originally, but the expense of importing it is considerable. Beds of it are known to exist in this country. None of the American material has yet been used for making powder, but it has been experimented with enough to show that it is fully equal to the imported article. The kieselguhr is prepared for use by first mixing it with a little water, and then baking it into bricks. The object of this is to dry the earth more effectually. When required for use the bricks are ground between rollers, carefully weighed into wooden tubs, and carried to the nitro-glycerine house.

The guhr for No. 2 dynamite is composed of nitre, sulphur, and rosin, and is made as follows:— The sulphur is pulverized in a revolving cylinder, at one end of which a blast of air enters, and passing through, carries the powdered sulphur into a tight box. The nitrate (either soda or potassa) is first dried thoroughly on an iron floor, then ground in a mill and passed into a box. The rosin is pulverized in a cylinder. The sulphur, nitre and rosin are then mixed in proper proportions and carefully weighed into wooden tubs.

Glycerine. The glycerine used is obtained from various manufacturers, who purify it by special chemical processes. It is always tested before purchase, and though it is generally found sufficiently pure, it is hardly ever of sufficient strength. For this reason, it is invariably found necessary to boil the glycerine in the vacuum pan, after it arrives at the powder works. Different glycerines, though equally pure and of the same strength, produce sometimes, nitro-glycerine differing slightly in appearance, though the same in nature and composition.

Acids. The acids are all obtained by purchase—principally from the "Lodi Chemical Works." They are now of the very best quality, though at first it was difficult to obtain them of sufficient strength. The immense quantity of nitric and sulphuric acid required, is a sufficient inducement to the chemical works to cause them to furnish the

very best article. At the dynamite works in California the Company make their nitric acid and they propose doing the same at Drakesville very soon, as a matter of economy. The acids are received from the manufacturers in carboys, and tested by the superintendent before being used. A sufficiently large stock of acids is kept on hand, but the facility with which they can be obtained renders a great accumulation unnecessary.

Exploders. The Company are now manufacturing their own exploders or caps, as they term them. They are small copper cases containing fulminate of mercury and a sensitive powder. The electrical fuzes are made water-tight by pouring melted sulphur in on top of the sensitive powder.

PROPORTIONS OF GLYCERINE, ACIDS, AND GUHR, IN NOS. 1 AND 2 DYNAMITE.

For the nitro-glycerine the following proportions are used :— Two parts of sulphuric acid are mixed with one part of nitric acid. For every seven parts of the mixed acids, one part of glycerine is added.

One part of nitro-glycerine is expected for every four parts of the mixed acids.

For No. 1 dynamite, three parts of nitro-glycerine (or 75 per cent.) are added to one part of kieselguhr. For No. 2 dynamite, between 36 and 36½ per cent. of nitro-glycerine is added to the guhr.

The guhr of No. 2 dynamite is made up as follows ;—

75 per cent. of nitrate (either soda or potassa).
12½ per cent. of sulphur.
12½ per cent. of resin.

The nitrate of potassa is preferred to the nitrate of soda, although much more expensive. It is termed "converted nitrate," being made from the nitrate of soda. The nitrate of potassa used by the Company seems remarkably pure, analysis showing but one part of impurities in three thousand. The soda is much more liable to absorb moisture and cause the powder to cake. The resin also, when subjected to alternate heat and cold, causes caking. Other materials, such as charcoal, common coal, etc., are sometimes substituted for the rosin. The addition of a little stearin is said to prevent this caking, although its use is not considered necessary.

RELATIVE STRENGTH OF NOS. 1 AND 2 DYNAMITE.

No experiments of a sufficiently definite nature have been made, to determine accurately the relative strength of the two compounds. For blasting purposes No. 2 is considered preferable, and its comparative cheapness makes the demand for it much greater than for No. 1. The Company claim that, though the guhr of the No. 2 has

really but little strength within itself, it becomes, when acted upon by the nitro-glycerine, a powder having about one half the strength of nitro-glycerine itself.

From this we may calculate the relative strength as follows:—

No.	Composition.	Relative strength of Components.	Relative strength as compared with pure Nitro-glycerine.
1.	75 per ct. nitro-glycerine. 25 per ct. kieselguhr.	75 0	75 per cent.
2.	36 per ct. nitro-glycerine. 64 per ct. guhr.	36 32	68 per cent.

No. 2 in its explosion, apparently produces more gas, but does not produce it as rapidly.

I witnessed the explosion of two cartridges, of about one half pound each.

First—a charge of No. 1 was placed upon a two-inch board and exploded. The result was a clear break, and few pieces.

Second—a charge of No. 2 was placed on a piece of the same board; the explosion was louder, the volume of smoke greater; the board was broken into small fragments and much scattered.

In appearance the powders are very similar; No. 2 having a slight yellow tinge, while that of No. 1 varies with the color of the kieselguhr, which is usually white, but sometimes tinted, owing to the presence of iron.

No. 2 dynamite is said to retain its nitro-glycerine even better than No. 1; it can be fired under water as readily, but under all circumstances it is a little more difficult to explode.

PROCESS OF MANUFACTURE.

The acids are received and stored in the acid house *A* (Fig. 2). The carboys are emptied, in proper proportions, into a lead lined tank (*a*) and thoroughly mixed. The mixed acid is drawn off into carboys and stored in the cooling-house (*B*). They remain here a sufficient time to cool thoroughly.

When nitro-glycerine is to be made, the mixed acid is taken from the cooling-house and emptied into a lead lined tank (*b*), in front of nitro-glycerine house. This tank has a graduated glass tube in its side showing the amount of acid it contains. From the tank (*b*) the acid is allowed to run into one of the nitro-glycerine machines (*c*).

The general construction of this machine is shown in Fig. 3. It is a wooden tank (*A*) with an interior lead tank (*B*). A hollow iron cylinder (*C*) is supported upon bearings at the side of the tank, and can be turned by the handle (*F*). Attached to the

same shaft, is a paddle wheel (*D*) which turns with the cylinder. The tanks are provided with a tight cover having two holes—one for a thermometer, the other for a pipe carrying off the disagreeable fumes generated during the mixing of the acids and the glycerine.

G is an elongated funnel having at its lower extremity about forty small holes. These holes or openings can be enlarged, diminished, or closed entirely, at pleasure. When in use, the funnel is placed over the iron cylinder and parallel to it. A can of glycerine is carefully weighed and placed on the shelf above the roller—a stop-cock allows the operator to keep the funnel full. During the process of mixing the glycerine and acids, the tanks are kept cool by a supply of water. This water is brought from a spring, and having a head of sixty feet, forces itself between the wooden and lead tanks and through the iron cylinder with great force. The spring furnishes an unlimited supply of the coldest water, and its head does away with the use of an engine.

The acids having been run into the tanks and the glycerine being in position, the mixing commences. The cold water is let on, the glycerine is allowed to run, and the cylinder is revolved. The paddle-wheel at *D* keeps the acid in motion, and the spreading of the glycerine on the cylinder causes the mixing to be very thorough. The thermometer is watched very closely and the temperature not allowed to run above 75°. When it attempts to do so the supply of glycerine is cut off, or reduced, until the temperature is lowered. Though no such case has yet arisen, the superintendent informs me, that if an attempt to reduce the temperature should fail, he would leave the works as rapidly as possible. When the supply of glycerine is exhausted (this operation usually taking one and a half hours) the cylinder is revolved a few times to clear off all traces of glycerine.

The nitro-glycerine is now made and ready for purifying. It is run off into one of the lead lined tanks (*D*) Fig. 1. These tanks are kept full of water and give at least six feet over the glycerine. The nitro-glycerine remains in this tank until it settles to the bottom. This settling is assisted by men with small wooden pats, who gently tap the particles as they rise to the surface. The time of settling varies with the quality of the glycerine, ranging from one half hour to several hours. After the settling is complete the water is drawn off and run to a hole in the ground, some distance from the works. The nitro-glycerine is then run into the lead lined tank (*E*), also filled with water which is changed three or four times, or as often as necessary to clear the nitro-glycerine of acid. A siphon is used for drawing off the water as it will clear it more effectually than a stop-cock. The operation of patting is continued throughout this washing.

After the several washings, an alkaline solution (sal soda) is added to the contents

of the tank, to neutralize any remaining acid. The contents of the tank are thoroughly stirred with a wooden rod. The nitro-glycerine is then tested with litmus, and if any trace of acid is discovered, the stirring is continued.

When entirely free from acid the explosive liquid is ready for mixing with the guhr. The mixture is made as follows:— On the floor of the nitro-glycerine house is a wooden bowl (*F*). This bowl is about six feet in diameter, lined with lead, and of the form of an ordinary chopping bowl. The kieselguhr for No. 1, or the mixture of nitre, sulphur, and resin for No. 2, previously prepared and weighed at the mill, is spread evenly over the bowl. The nitro-glycerine is drawn from the tank in iron pails, weighed, and poured upon the guhr. Three men with wooden rakes and shovels, mix and mix until the nitro-glycerine is evenly distributed throughout the guhr. After this mixing the powder is worked through ordinary sieves by hand. It is now ready for making into cartridges, and is carried to the packing house.

PACKING.

The cartridge paper is prepared by oiling with ordinary linseed oil: it is then made into cases of the required size. The men and boys, who make the cartridges, sit at a bench with a tray of powder in front of them; an ordinary funnel is put in the top of the case, and with a round, wooden stick of the proper diameter, they scrape in the powder and ram it gently. The cartridges, as fast as made, are packed in boxes, ordinarily containing fifty pounds—sometimes one hundred pounds. They are then strapped with iron, and taken to the magazine or shipped.

Of the process I have above described, I only saw the mixing of the powder, and the packing of the cartridges. We arrived at the works too late to see the glycerine machines in motion. The nitro-glycerine was in the large tanks, and from this time on I watched the operation. The nitro-glycerine as it was drawn from the tanks presented a milky appearance. The superintendent informed me that it sometimes came out white and sometimes colorless; he attributed the appearance to a little water, and stated that if it was allowed to stand, it would clear itself in a short time.

CAPACITY OF THE WORKS.

At present, although an immense quantity of dynamite can be manufactured, the works cannot be said to be very extensive. To double or treble their capacity would be an easy and rapid operation. The apparatus is all simple and could be made in a short time. They now have two nitro-glycerine machines—one using 1,500 pounds, and the other 1,050 pounds of the mixed acids. These machines are entirely independent of the

cleaning apparatus, and can be worked over and over; the resulting nitro-glycerine being run into the tanks as fast as it is made.

The foreman assures me that he can make three batches before one o'clock, and could, if necessary, make five or six batches in a day.

Allowing one pound of nitro-glycerine to four pounds of mixed acids, we will have for—

One batch 637.5 pounds nitro-glycerine.
Three batches 1,902.5 pounds nitro-glycerine.
Five batches 3,187.5 pounds nitro-glycerine.

or, taking five batches as the extreme limit, we would have for a day's manufacture with present machinery—

4,250 pounds of No. 1 dynamite.
8,854 pounds of No. 2 dynamite.

The kieselguhr is the only ingredient which is not an article of commerce in the United States, and which cannot be obtained at a moment's notice. The Company have, and always intend to keep, a large supply on hand.

The above indicates the present capacity of the works. Additional nitro-glycerine machines and washing tanks would increase the supply beyond limits. The operation of making dynamite is too simple, and the desire of the Company to accomadate their customers too great, to fear a dearth of the article when occasion arises for its use.

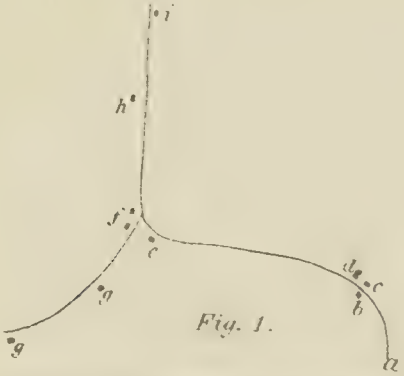
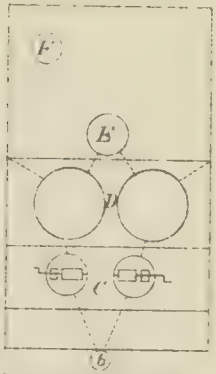
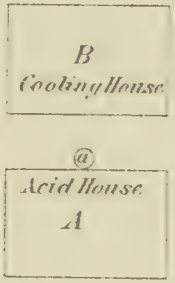


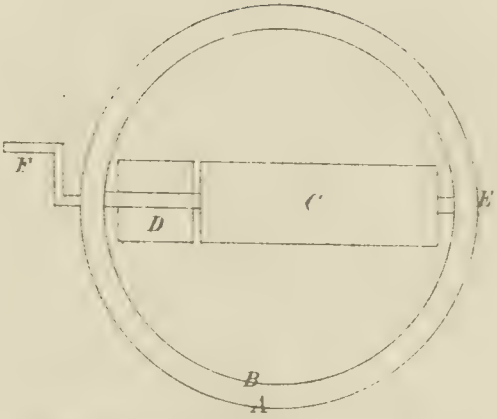
Fig. 1.

General arrangement of the works.

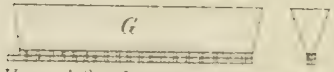


Nitroglycerine House
Fig. 2.





Machine for mixing Glycerine and Acid.



Funnel for dropping Glycerine on cylinder.

Fig. 3.



Section through cylinder with funnel in position.

THE FIRE-ALARM SYSTEM

OF

NEW YORK CITY.

READ BEFORE THE ESSAYONS CLUB OF THE CORPS OF ENGINEERS,

MARCH 2, 1874;

BY

LIEUT. WILLIAM H. BIXBY,
CORPS OF ENGINEERS.

NO. XXIX. PRINTED PAPERS.

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NOTE.

This paper was prepared in compliance with instructions issued from the Headquarters of the Battalion of Engineers—under approval and direction of the Hon. Secretary of War and the Chief of Engineers—directing each officer of the Battalion to visit and examine, during the winter suspension of drills, some specified public work or manufacturing establishment. By request it was read before the Club; and being considered to contain information of interest to Engineer officers, it was ordered to be printed.

This note is prefixed by a vote of the Club, in order to explain the peculiar character, and necessarily limited scope of the paper.

THE FIRE-ALARM SYSTEM OF NEW YORK CITY.

A paper read before the "ESSAYONS CLUB" of the Corps of Engineers, on March 2nd, 1874, by Lieutenant William H. Bixby, Corps of Engineers.

Fire-alarm systems are of two kinds; the Automatic system and the Central Office system. The former is fully adapted to the wants of smaller places, but in large cities, such as New York, the latter system must be used. This system differs from the automatic in that all alarms from the signal stations are transmitted no farther than a central office where operators, on duty day and night, receive the signals and set in motion the apparatus which repeats the alarm upon the bells and gongs distributed throughout the city in engine-houses and upon churches. This system requires several lines, and consequently needs the presence of several men at the central office to receive and transmit the alarm, as well as the services of other men to look after these lines and keep them in constant repair. The automatic system, however, dispenses with the necessity of employing but one or two men in all; it is therefore much cheaper, and should be used in every case where the surroundings are favorable.

When the lines of the fire-alarm department are nearly the only telegraph lines running through a city, its circuits will remain in order for a long time with but little attention, and here the automatic system can be advantageously used; but in a large city like New York, crossed in every direction by metallic wires, this system would be all the time getting out of order, causing great trouble; the Central Office system therefore becomes a necessity, and in consequence has been adopted.

The fire-alarm system is of very great advantage to the community at large; it furnishes every property holder with the means, near at hand, of giving an instantaneous definite alarm, saving much property and, in many cases, human lives; it obviates the necessity of turning out the whole department at every fire: that portion only, which is nearest the signal box where the alarm was sounded, need respond. In each street box there is a telegraph key by the use of which the chief engineer or his assistants can summon any additional force which they may require. In case of necessity the telegraph

may also be used for a similar purpose by the police, who employ a suitable code of signals. The system may be used to establish standard time throughout a city by simply connecting the telegraph line with some standard chronometer.

The fire-alarm telegraph is designed: first, to enable any person to send a quick, reliable alarm of fire to a central station, indicating the neighborhood of the fire; and secondly, to enable the receiver of such message to transmit it instantaneously to such points, principally engine-houses, as may be deemed necessary. This system should always be in perfect working order so that the message received will be positively reliable; the assistants in the central office should at all times be posted as to the condition of each and every telegraphic circuit of the system, and should know instantly when any line becomes out of order. Moreover a record of the fires and of each day's work should be made out and preserved. These requirements can be fulfilled by means of the apparatus in use in the New York Fire-alarm System. Let us see how it is done. The fire-alarm system proper consists of: first, the receiving portion whose different parts are its batteries, office connections, switch-board, annunciator, register, sounder, alarm-bell, street lines and automatic street signal-boxes; secondly, the sending portion, composed of its batteries, office wires, the transmitter, line wires and mechanical gong strikers; thirdly, the testing apparatus, comprising galvanometers and rheostat, with conveniences for making the requisite connections. In addition to the above, there are two dial telegraph circuits for the fire department; another of the same kind for the use of the police; two tower circuits running to eight church towers in different parts of the city and four talking circuits connected with the engine-houses.

A separate room is devoted to the batteries. The rest of the apparatus at headquarters is concentrated into a single room where everything is conveniently arranged for receiving, sending and testing. Here are constantly to be found two operators; six are employed in all; they serve in couples, each set remaining on duty eight hours out of every twenty-four.

The different parts of the system will be taken up in succession.

Batteries. As there are a great number of separate circuits, each requiring a separate battery, the room containing these batteries is quite extensive and requires the constant attention of three men to keep it in proper order. The different batteries are arranged on shelves when they can be conveniently inspected, and the total array of nearly nine hundred cells is quite imposing. These cells are grouped as follows:—

41	Street-box circuit batteries averaging each		12	Hill cells.
2	Dial	do. do.	37	do.
4	Talking	do. do.	18	do.

2 Tower circuit batteries averaging each 26 Hill cells.
1 Police do. do. 8 do.
An auxiliary battery to reinforce any line while in special use, of 40 Hill cells.
Testing battery for gong circuits, of 5 do.
For 7 gong circuits, one battery acting on each circuit in succession, 38 Chester Electropoion cells.
2 Side Register batteries, each 24 do. do.
Local battery for sounder, bell and vibrating alarm, 12 do. do.

Besides these there are several auxiliary Hill batteries and one Electropoion battery which are not in constant use but can be called upon in case of emergency. All the above batteries vary slightly in the number of their cells proportionally to the amount of resistance in their circuit; the number being so regulated that the current through the circuit will be sufficient to ensure reliability of signals. The street box circuits average about two hundred and eighty ohms resistance.

The Hill cells are used upon the closed circuits where constancy of current is required; and the Electropoion battery is employed with the open circuits where a great quantity of current is to be used through a large resistance, but only occasionally and then for but a few moments.

The Hill cells have to be renewed every month or two. They work very satisfactorily. Slight modifications have been tried and it has been found an improvement to put the copper plate above the copper sulphate crystals instead of below, and to *screw* the zinc terminal into the zinc plates instead of driving it in as had been done formerly. Another experiment was to place the zinc plate in a porous cup at the top of the cell, still retaining the copper plate above the crystals. This was much more satisfactory. Occasionally copper was deposited in a pure state upon the sides and bottom of the porous cup, tending to crack the latter; in every case, this deposition was found due to contact of the zinc with the inside of the cup, and destroying this contact obviated further deposition. The Electropoion battery, so called, is a double fluid (bichromate of potash and acid) battery, with carbon and zinc plates. It is a powerful battery but requires a great deal of attention. The bichromate solution is placed in a porous cup around the carbon pole; every second day a portion of this solution must be removed by a syringe and new substituted. The porous cup is surrounded by sulphuric acid diluted with fourteen parts of water; this mixture is contained in a glass jar, and needs to be changed every week. The bichromate solution is called electropoion fluid, and is made by adding six pounds of bichromate of potash to one gallon of hot water, stirring it well; when

cold, add four gallons cold-water and one gallon sulphuric acid.

Tripping Batteries—automatically plunging the plates into their respective solutions, were formerly employed in connection with the tower bells, but they have now gone out of use.

Lines. The lines are as indicated above under the head of batteries. All the circuits are metallic throughout; no grounds are employed except for the purpose of testing. The lines outside of the building are common telegraph lines, consisting of naked iron wire, of from 13 to 18 ohms resistance per mile, with glass insulators. The circuits passing through the switch-board, fifty-two in all, are the—

41 Box circuits, each connected with about 23 street boxes.

4 Talking circuits connected with different engine-houses, and over which the companies report their return from a fire.

7 Gong circuits connected with the alarm-gongs in the engine-houses.

Formerly the alarm was sounded upon the bells of church towers, but this practice has been discontinued by order of the city.

The three dial and two tower circuits have already been explained. At each of these towers is stationed a watchman whose duty is to always remain upon the lookout for fires. At stated hours during the day the roll of church towers is called by telegraph and each watchman must immediately answer.

The box circuits run throughout the city and are so arranged that, in general, two consecutive boxes shall belong to different circuits. An accident to one circuit will then produce as little trouble as possible; for if one box cannot be used, the next will be available since it will be upon a different circuit probably in order. Lightning arresters are placed wherever there is a set of magnets; viz: at the ends of the wires where they enter the central office, street-boxes, or engine-houses.

Office Connections. The lines are brought over the top of the building from two different sides, both ends of each circuit coming directly into the operating room by its window, one end on one side, the other end on the other. On the outside of the window each naked wire enters one binding post of a lightning arrester, the other binding posts being joined together and connected to earth by a lightning rod running outside of the building. The wires themselves, just before entering their respective binding posts, are kept from touching the wood-work of the window by each wire being run in the groove made in and around a small ivory knob projecting from the wood-work. Unless something of this sort were done, the wet wood, in rainy weather might form a good electrical communication between the various lines, making crosses and giving rise to a great deal of trouble. At the lightning arrester, the office connections are attached to the

outer lines. These connections consist of insulated copper wires, each set of eight having a cover of different color from the rest, to furnish an easy mode of identification, in case of necessity. A very simple and pretty arrangement is used to keep the wires separate and yet readily accessible and each in full view if desired. On each side of the window is a long board extending from the top to the bottom of the room and having a sufficient number of grooves cut in it; each groove runs the entire length of the board and is just large enough to receive one wire. At intervals are narrow cross-pieces to keep the wires from rising out of the grooves; on the raised portion of the board beside each wire is put its number so that any wire can be identified instantly. In this manner the office wires run to the switch-board. The same general method is employed, when practicable, for all other connections. Where the wires run under the floor the boards are arranged in sections, which are hinged and furnished with handles so that they can be easily raised.

The office itself is not very large, but still there is plenty of room for the operators. Everything appears to have been arranged with an eye to convenience. The switch-board occupies one end of the room, the receiving apparatus is placed upon one side and the transmitting or sending apparatus on the other.

Switch-Board. The switch-board is a large and handsome affair and is very conveniently arranged. It is about nine feet long and three feet high and rests upon a table whose top is about two and a half feet from the floor. Upon this table and at the bottom of the switch-board is placed a series of small galvanometers, one for each circuit; and in addition, one galvanometer through which any battery can be short-circuited. The switch-board is of slate resembling in appearance a black and veined marble. The switches are of brass; their bearing surfaces are thickly faced with platinum, as also those of the knobs upon which the switches rest. The surface of contact is about an eighth of an inch square. The switches are arranged in fifty-six vertical lines of eight switches each; the upper four of each set belonging to one end, the lower four to the other end of the corresponding circuit. The fifty-six vertical lines are further arranged in groups of eights for convenience in identification. The galvanometers are, as stated, small; their needles are about an inch long; each galvanometer is numbered according to its circuit so that any particular one can be readily found. In the centre of the board a small portion is devoted to switches for the various auxiliary batteries. The general arrangement of the switch-board is shown in the accompanying plate, Fig. I. ABCD are the switches belonging to one end of one of the circuits; $A_{,}$ $B_{,}$ $C_{,}$ $D_{,}$ are the switches belonging to its other end. 1 2 3 4 5 6 7 8 are buttons upon which switches ABCD may be placed; $1_{,}$ $2_{,}$ $3_{,}$ etc., the buttons that may be covered by switches $A_{,}$ $B_{,}$ $C_{,}$ $D_{,}$.

The ends of the line wires are connected to A and A,; the poles of the battery to D and D,. The galvanometer is inserted between button 3 and switch C. The switches are marked with raised letters according to their use. Switches A are marked "earth," B, "repeater," C, "reserve battery," and D, "tests." Buttons 4 and 4, are no longer used. Formerly it was the custom to send the alarm back over all the box circuits; the buttons 4 and 4, were then connected with the transmitting apparatus and the movement of the switches B and B, from 3 and 3, to 4 and 4,, changed the circuit from a receiving circuit to a sending one. These switches were then connected by a cross bar in sets of eights, so that a single movement changed each set. An examination of the diagram will show that nearly all possible combinations required between batteries, lines galvanometers and grounds, can be made readily by a few movements of the hand.

RECEIVING APPARATUS.

The whole apparatus for receiving is situated upon a large table and is, moreover, very conveniently arranged. At the centre of the front of this table is the register; on either side a series of relay magnets, one relay for each circuit; at one end of the table the two dial telegraphs for the use of the fire department; at the other end, the other dial for the service of the police. Behind the relays are a series of stops, numbered and so arranged that each on being pulled out will reinforce its particular circuit with the auxiliary battery.

Above this arrangement of stops is a row of telegraph keys, one for each circuit; above these, the annunciator which shows instantly the number of any circuit over which a message happens to come; on top of the annunciator are two local sounders, two bells and one vibrating alarm. One of the local sounders is so connected with the circuits that the operators in the office can hear anything that may be sent over any and all of the lines; the bells can be used if preferred; the vibrating alarm is used during the night as an additional safeguard.

Annunciator. This is a simple arrangement consisting of a series of magnets, one interposed in each circuit; the armatures carry pins upon which rest small slides. When each circuit is completed, each armature attracted by the magnets, holds up its slide; when the circuit is broken the attraction ceases; the armature is pulled away by a spring, withdrawing the pin from under the slide; the latter falls and shows, through a small opening in the front of the annunciator, the number of that particular circuit. These annunciators work well for the fire-alarm service. When any slight jar shakes the annunciator, one or more of the slides often fall; a single movement of a handle will however replace all of them. As the slide never fails to drop when a real alarm comes, its falling down at other times is a fault of minor importance to the oper-

ator because any real alarm will also record itself numerically upon the register.

Register. This is the apparatus by means of which all the alarms are recorded. It was originally intended to register everything that passed over the lines, but, after a fire, or while the repairers are at work, there is so much conversation going on, which is needless to record, that the register is now allowed to act automatically only when something especial, such as an alarm of fire, is received. The machine is, however, capable of doing all it was originally intended to do.

The instrument consists of fifty-six sets of relay magnets, each attracting or releasing its own armature ; the latter, in turn, lowers or raises a pen which is placed above a moving sheet of paper. In this way each pen records upon the paper every break in the circuit with which it is connected by a relay. The pen is made in the form of a thin circular disc of steel, which rolls by contact with the moving paper ; at the same time it is inked by rubbing, as it moves, against another roller wet with ink by a reservoir above. The paper is in the form of a continuous roll about ten inches wide ; it is unwound automatically as needed, and is kept tight by being coiled up again on another cylinder which is actuated by a spring. The only attention the instrument needs is to be wound up once or twice a day and to have ink and paper supplied every two or three weeks. The main cylinder on which the paper moves in its passage through the instrument, is driven by a weight ; its motion is regulated by the aid of clock work and a fly-wheel ; the fly-wheel is generally prevented from moving by a detent which is nearly balanced by a weight. When any one of the fifty-six circuits is broken, a relay worked by the local battery withdraws this detent ; and when the signal circuit is again closed, the balancing weight gradually brings back the detent to its former position, stopping the motion of the fly-wheel and therefore that of the main cylinder after the paper has moved one or two inches beyond the last mark of the pen. To keep out dust the register is covered with a glass case. Every eight hours when the operators are changed, the paper, used during the tour just finished, is cut off ; it is marked with the time of commencement and end of the tour, and is then filed away for future reference. It was originally intended to connect the register with a clock and, by the aid of the latter, to print the time of day upon the register at the beginning of each hour. This however has not been done. Neither is the hour of noon sounded throughout the city on the tower bells by the fire department, as is done in many other places.

Street-Boxes. These boxes form a very important part of the system. They are fastened to the telegraph poles and engine-houses and consist of an outer casing or house of iron protecting the interior mechanism. On the outside are printed or painted directions, telling where the key of the box may be found. Upon opening the outer door,

another door is seen from which projects a handle; the pulling down of this handle sends the alarm, and the number of this box is then automatically transmitted to the central office without any further action on the part of the public. The key to the outer box is furnished to policemen, patrols and firemen, as well as to the proprietor of some store in the immediate neighborhood. The key of the inner box is however only possessed by the officers of the fire department. Inside the latter box is the automatic alarm-signal maker, a Morse telegraph key, a relay and bell; also, a lightning arrester, and a switch by means of which either or both ends of the wire entering the box may be connected with the ground. Any officer of the department can therefore communicate with headquarters from any street-box, by the use of the Morse alphabet or any code of signals previously agreed upon.

The alarm-signal maker is a clock-work mechanism whose motion is regulated by a fly-wheel; it is wound up by pulling down the handle on the outside of the inner door; this handle, on being pulled down, engages an arm connected with the axis of the driving wheel, and the movement of the arm winds up the enclosed main-spring. When the handle is released, a spring pulls it back to its original position and the clock-work commences to move. The motion continues until the arm, above referred to, rises high enough to again engage with the handle, and this motion is sufficient to allow the alarm to be sent three times. The method in which the signals are made is as follows: One of the wheels carries upon its axis two circular parallel disks placed near together and having between them a good metallic connection. A spring connected with one end of the circuit presses upon the circumference of one disc; another spring insulated from the first and connected with the other end of the circuit presses in like manner upon the circumference of the second disc. When these two contacts are maintained the circuit is closed; the circumference of one disc is cut with notches so that when the disc is rotated, the circuit will be broken every time a notch passes the spring which presses upon that disc. For illustration, if on the circumference of one disc is cut one notch, a little ways from it two notches, and further on five notches, then as often as the disc completes one entire revolution, the circuit will be broken once, then twice, then five times; every relay upon this line will click at every break, and the number 125 will thus be sent to the central office. Upon the circumference of the disc which we have taken as an example, the interval between the five notches and the single notch must, of course, be greater than elsewhere, in order that the repetitions of the number shall be distinct from each other. Every box has its own number. As before stated, there are about twenty-three boxes upon each circuit, and the total number of boxes throughout the city is over nine hundred.

The bell in the inside of each box, forming with its magnets a portion of that particular circuit, will ring as the circuit is alternately broken and made, and in this way, will inform the sender of the alarm that the number of the box is correctly forwarded to the central office.

THE SENDING APPARATUS.

This includes the transmitter and the mechanical gong strikers. By the former the alarm is sounded upon the latter, each alarm being repeated three times.

Transmitter. This is a piece of mechanism, consisting of two trains of clock-work each driven by a separate weight. One set of wheels is to make and break the alarm circuits at the proper intervals so as to transmit the required alarm; the other is to preserve a given interval between the repetitions of the same alarm; this interval equals that during which the driving wheel of the second train completes one revolution. The instrument is arranged for forty-eight circuits grouped into six sets. Only seven gong circuits are now used; the instrument will however be described as if one entire set of eight were employed.

The first train of wheels has two main axes; upon the principal axis is placed by the operator a small wheel called the "regulating wheel," which throws the battery into circuit during certain intervals of time; these intervals correspond to from one to nine complete revolutions of the secondary axis. This secondary axis has upon it eighteen disks, arranged in two sets; each set of nine disks is insulated from the other, and the outer disc of each is always in contact with a spring through which the battery current comes from, or goes to, that set of disks. The remaining eight disks of each set have upon them one tooth apiece; the teeth of the different disks are arranged spirally around the axis so that at every revolution of the latter, each tooth in succession will press once against a spring connected with one end of one of the gong circuits. These springs are insulated from each other; there are eighteen of them, one placed above each disc, and each is connected with one of the eighteen wires coming from the two poles of the battery and the two ends of the eight gong circuits. The two sets of disks are arranged symmetrically, so that the two springs forming the ends of the same gong circuit will be touched at the same instant, each spring by the tooth of a disc in the set over which the spring is situated. The electric current, coming from one pole of the battery through one of these outer springs, can then pass through this spring and its disc, to the rest of that set of disks; through the tooth which happens to be touching a spring to the corresponding gong circuit; through this circuit to the spring which forms its other end; through this spring and the tooth which, at this instant, it must touch, to

the second set of disks; and through the outer disc and outer spring to the other pole of the battery.

The regulating wheel, placed by the operator upon the principal axis is different for every number which is to be sent by the transmitter. It throws the battery into circuit by having, on its circumference, projections pressing together two springs, which, while separated, form a break between one pole of the battery and the spring bearing upon the outer of one set of disks; it also presses together two other springs which bear the same relation to the other pole of the battery and other set of disks. The bearing surfaces of all these springs are heavily faced with platinum as also the ends of the teeth of each set of disks. The surfaces of contact on the springs is about an eighth of an inch square; upon the teeth about an eighth of an inch one way and a quarter of an inch the other.

To illustrate the above description, suppose the alarm number one hundred and forty-five is to be sent. The operator takes from a drawer the corresponding regulating wheel and places it upon the principal axis. This wheel has upon it three teeth, one for each number; the second tooth is equivalent to four of the first, the third tooth to five of them. When the mechanism is started by the operator, the first tooth during one revolution of the secondary axis presses together the springs connecting the two poles of the battery with the two sets of disks of the secondary axis, and as the latter axis revolves, the battery circuit is completed for an instant through each of the eight gong circuits in succession. The first tooth of the regulating wheel having then passed its springs, the battery current is cut off while the disks revolve twice; the next tooth throws the battery in action during four revolutions of the disks; the battery current is again cut off and after another pause the third tooth throws it in circuit once more while the disks revolve five times. As these three teeth come around a second and a third time, the same operation is repeated, and in this way the number one hundred and forty-five is rung out three times upon each gong circuit. The regulating wheels are all of the same diameter; the length of the outer circumferences is then the same for all. However the arrangement of the teeth, of course, differs for every number. Now suppose we compare the wheels corresponding to the numbers 111 and 999; the teeth of the first will extend over only a small portion, but those of the latter over nearly the whole of the circumference of the wheel. The interval between repetitions of the signal would then be different in these two cases. The second train of wheels is to obviate this trouble and to make these intervals between repetitions the same for all numbers. The first train is arranged to stop itself at every complete revolution of its principal axis. Each regulating wheel carries a pin projecting from its side and placed beyond the last of its teeth. As soon as

the last number has been sounded for the first time, this pin comes in contact with and lifts a lever, permitting the second train of wheels to revolve. At the same time a projecting arm of this lever removes from the fly-wheel of the first train of wheels, the greater portion of its fan; this allows the first train of wheels to revolve at a much increased speed until its principal axis has completed one entire revolution; at this point the motion is stopped automatically by the aid of a detent and friction brake. Meanwhile the second train of wheels is still in motion, but, in its turn, it stops itself, as did the other, at the completion of one revolution of its driving wheel. Just before stopping, a pin connected with this wheel pushes aside, by the aid of a lever, the detent of the first train of wheels and the whole operation is then repeated. The third time, however, the first train of wheels locks itself in such a manner that nothing but the hand of the operator can again put it in motion.

If desired the mechanism can be arranged so as to send the alarm any other given number of times instead of three, as is desired. At present three alarms are considered sufficient.

Mechanical Gong-Strikers. These are placed in each of the engine-houses. There are two kinds employed; in each the motive power is a weight acting, through a clock-work arrangement of wheels, upon a hammer which strikes the gong. An arm connected rigidly to the hammer rests upon a detent which is attached to a soft iron armature. When an instantaneous current of electricity passes through an electro-magnet forming part of the instrument, the armature is attracted, the detent is withdrawn and the hammer falls upon the gong; the driving weight by means of the clock-work, immediately raises the hammer to its former position; the detent is pulled back under the arm of the hammer by a spring and the arm itself comes in contact with a projection on the driving wheel stopping the latter's motion. The mechanism is then ready for a repetition of the same operation. In one of the gong-strikers the driving wheel has in it an eccentric cut in which plays a projecting pin on the arm of the hammer. In the other arrangement, a wheel carries an arm with a projecting knob; in the latter part of the revolution of the wheel, this knob engages with the under side of a curved guide so placed on the arm of the hammer that the motion of the arm of the wheel lifts the hammer. The gongs are quite large and the hammers weigh two or three pounds. Besides these larger gongs placed in the engine-houses, there are several smaller gongs or bells placed in various buildings and rooms of the department. In the latter, the hammers, which are light, are fastened directly to the armatures.

Engine-Houses. These houses are placed in different parts of the city, and any one may be taken as a fair example of them all. As the firemen and horses must remain

in them ready for action day and night, they comprise an engine-room for the engine and hose carriage, a stable for the horses, and a dormitory and reading-room for the men. The first two are on a level with the street, the reading-room and office of the captain are up one flight of stairs, while the dormitory is upon the third floor. As a general thing the horses stand free in their stalls, since the practice of fastening them up has been found unnecessary. If, however, they should happen to be fastened, the single movement of a handle, two of which are at the side of the engine-room, will free them. The horses are always kept with their harness on, and they are so accustomed to their duty that upon the first stroke of an alarm, they will rush out of their stalls and put themselves at once in their proper places. Everything is arranged to economise time; three movements only are required to hitch up each horse, one to fasten the pole-strap and two to attach the traces. The engine is kept prepared for immediate action; the fuel is ready, needing only the application of a torch; the boiler is always supplied with water heated to nearly the boiling point by the aid of a stove in the basement below. Two iron water pipes from this stove come through the floor and are connected with the boiler; the water is kept warm by a continual circulation through these pipes; two movements made by the fireman as he throws his lighted torch under the boiler, sever connection with these pipes and in a few moments his steam-guage indicates a plentiful supply of steam. To show the celerity with which all of these movements are executed, the men were gathered around the stove where they would ordinarily be sitting, and the gong was struck as if for a real alarm. In nine seconds from the first sound the horses were in position and harnessed; had it been a real alarm, in less than fifteen seconds the engine, hose-carriage, men and all would have been out of the building and well started towards the fire. Upon being unharnessed the horses went quietly back to their respective stalls but apparently with considerable reluctance.

Four telegraph wires enter each engine-house; two connected with the gong circuit, two with the talking circuit. At the various headquarters two other wires also enter connected to the dial telegraph instrument.

The reading-room is commodious and pleasant. It is probably about thirty feet long and twenty wide, and the walls are hung with pictures and engravings. On a centre-table are pamphlets and periodicals, and at one side is a library of moderate size.

The sleeping apartment is situated above and the room is arranged much like army barracks. The bedsteads are of iron; the beds are arranged around the sides of the room, and look plain but neat; above each on the wall is a small set of shelves.

As the men are liable to be called out at any hour of the night they sleep in their underclothes and blouses; their trousers and rubber boots are placed at the side of the

bed, the legs of the trousers being strapped to the outside of the boots, so that each man can dress himself completely while jumping from his bed and rushing down stairs.

Having described the different parts of the fire-alarm system and the different buildings, suppose now that we take the case of a real fire and see what is done. The man who discovers the fire rushes for the key of the nearest street-box; this key he gets from the store nearest the box or from the first policeman he meets. He then rushes to the box, opens it, pulls down the handle and his part of the work is done. At the central office, the operator hears this alarm rung out by his sounder; at the first tap a slide of the annunciator drops, showing the number of the circuit; he steps to the register, moves a switch and the number of the box is printed on the moving paper thrice; he makes two more steps, takes from a drawer the corresponding regulating wheel, places it upon the principal axis of the transmitter, touches a couple of buttons; the transmitter starts, and the number of the street-box from which the alarm was sent is rung out in every engine-house in the city. In from twenty to thirty seconds from the pulling down of the handle in the street-box, the engines have left their houses and are on their way to the fire.

TESTING APPARATUS.

In a system where there are so many batteries, lines and instruments in constant use, they are all of them liable at any moment to get out of order. On this account the whole system should be often tested, so as to keep it in as good condition as possible. In a large city like New York trouble is continually caused by the crossing of the lines with the different wires that traverse the city in different directions. Several line repairers are constantly at work and even then it is difficult to keep everything in perfect order. In this respect however, the fire-alarm system possesses great advantages over other systems of lines. In the first place, their circuits are all metallic; in the second, these circuits are readily accessible at a large number of points, such as the street-boxes; and in the third place, a ground connection can be made at each of the latter points by the simple turning of a switch. Since the circuits are all metallic throughout, a single accidental ground connection will cause but little or no effect. Two or more grounds may combine to produce trouble, but this is the exception and not the rule. The same result follows from contact with lines of other telegraph systems. A single contact does no harm; several contacts may, however, cause the messages over one of these outside lines to be sent through the central office of the fire-alarm department. The signals thus received are so irregular and so different from a real fire-alarm signal that no great trouble results. The operator is immediately made aware of the existence in his system of some foreign element which he proceeds to remove as soon as practicable. In the

central office everything is thoroughly tested twice a day, at eight A. M. and at two o'clock P. M. The method of testing is as follows:— First, the operator rattles in succession each of the keys above the register; if the local sounder replies accurately to every touch, then the relays in each corresponding circuit must all be properly adjusted; if the sounder does not respond clearly to the touch on any particular key, then the relays of this circuit are examined and adjusted until a satisfactory result is obtained. This examination shows that the office connections and instruments are in proper condition. He next proceeds to the switch-board, and, taking each circuit in succession, switches each battery into a short circuit passing only through the central galvanometer; he records the deflection in each case and compares this set of results with a standard set. This examination shows the condition of each battery. He then tests each circuit with its own battery in three different ways, using the switch-board in making the requisite connections. In the first place, replacing the switches, putting them in their former position, so that the battery current traverses the entire circuit including the street-boxes instruments; he observes the deflection of the galvanometer and compares it with what it ought to be; any deficiency of deflection will show increased resistance at some point of the line, Secondly, he introduces into the circuit a ground placed first on one side of the battery and then on the other; if the galvanometer needle remains unmoved there is no ground made by the circuit at any other point; if, however, the needle moves, another connection with earth must exist somewhere, and a comparison of the two deflections obtained by introducing the ground on different sides of the battery, will show approximately the position of the fault. This ground may be made by a cross with some telegraph line which has a ground in its own circuit; if so, and the latter line is in operation at the moment, the messages sent over the intruding line will be heard upon the local sounder in the central office. Thirdly, the operator places both ends of the line to ground, cutting off the battery entirely; he then looks to see if any of the other galvanometer needles are affected by this action: if so, crosses must exist between the line experimented with and the one affected. If the galvanometer of the line experimented with does not show an absence of current, there must be a cross with some line in operation. If however, all these tests give satisfactory results with one circuit, the operator passes to the next, and so on. Any line that is troublesome is put upon the side registers. The latter consist of two Morse sounders, each connected with a powerful battery, one pole of each battery being put to ground. These batteries are sufficiently strong to work through a large resistance. If the circuit placed upon the side register does not make ground at the fault, a ground is then intentionally introduced by the aid of the street-box nearest the seat of trouble; the circuit will then remain in good working

order and can be attended to by the line repairers at any convenient time thereafter. The position of the fault can be located from the office, if necessary, by using a differential galvanometer and a set of resistance coils which may be connected, at pleasure, with the side registers. It is found much more convenient, however, to approximate to the spot where the trouble occurs; then to put one pole of the battery to ground, and let a line-man proceed from box to box, switching on a ground momentarily at each place, until the movement of the galvanometer needle at the central office shows that the fault has been passed. The same general method is used when there is a cross between two fire-alarm circuits. Both ends of one circuit and one end of the other are put to ground and the line-man passes from box to box as before and with similar results. The line-man, in these cases, communicates with the central office by using the telegraph key in each box, employing the Morse alphabet. On account of the convenience and simplicity of this method of hunting out any trouble along the line the differential galvanometer and rheostat are seldom used. A slide rheostat was formerly employed, but it soon got out of order and has been abandoned. In addition to the above methods of testing, it is customary to send out a man, from time to time, to go to the street-boxes in succession and pull down the handle of each. If everything is in order the alarm should be correctly received at the central office as each handle is pulled. Before sending the alarm in this way, the box-puller of course calls the central office from each box and tells the operator what he is about to do, to prevent any misunderstanding; otherwise the alarm would be received as that of a real fire and the operator would act accordingly.

The transmitter requires occasional testing in order to show that all its springs make good connections with the teeth of the revolving disks. To facilitate this testing an axis is arranged at the back of the instrument so that as it is turned it will successively break connection between each set of eighteen springs and their eight gong circuits, and will substitute for the latter, eight short circuits each including but a single set of magnets; the armatures of these magnets carry hammers which strike upon the plates of a metallophon sounding the gamut in the regular order of its notes. Each set of springs is tested in turn, and if in each case the gamut is correctly sounded, the springs must make the required contact with the teeth.

Similar to the Fire-alarm System but conducted on a smaller scale, is the American District Telegraph. The simplicity of the latter system compared with that of the Fire-alarm Department, makes it deserving of a short description. This telegraph is carried on by private parties, who, in New York, divide the city into districts and establish a small central office in each. From each office run a number of circuits, each comprising from

sixty to eighty small alarm instruments placed in different stores or buildings. Should the occupants of the latter wish the services of a messenger, they have only to press for an instant a button on one side of the instrument; if of a policeman, a button upon the other; or, in case of a fire, to press either button five times in succession. At the central office there are always a number of errand boys, who are immediately despatched in accordance with the message received. Each store or building has two numbers, one for a messenger, the other for the police; and either one number or the other is sent automatically by the instrument according to which button is pressed. This number is received at the central office upon a Morse register; the operator then goes to a series of drawers, numbered and conveniently arranged for reference; he pulls out the drawer corresponding to the number received, takes from it a printed blank containing the number of the building and the names of its proprietors; writes upon it the time of day and gives it to any messenger in the office, who proceeds to the building designated, either alone, or accompanied by a policeman, as desired. In case of fire, the messenger is hastily despatched to the street-box nearest the building from which comes the alarm.

The different parts of this system are its batteries, office connections, switch-board out-door circuits, alarm instruments, local relays and Morse registers.

At the office visited, the batteries were all neatly arranged upon a series of shelves so that each cell was in plain sight and could be readily examined at any time. The only kind of battery used was the Lockwood. The cells presented a handsome appearance. One battery had been set up for nine months without having been touched during this time; it was still in working order and looked well, although pretty nearly used up. The lower copper spiral was almost entirely gone; the vertical post and upper spiral were much increased in size from the deposition of the copper; the zincs were honeycombed and looked as if they might fall in pieces at any slight jar.

The office connections also were neatly arranged; the wires were fastened to the wall and ceiling by strips of wood. These strips are made by taking two narrow pieces, and planing them so as to fit closely together; they are then separated and across the surface of one are cut narrow grooves placed at equal distances apart, each deep enough to contain a wire. The office connections can then be placed in these grooves, the top piece screwed to the lower and the whole is ready to be permanently fastened to the sides of the room. In this way the wires occupy but little space, are out of the way, are distinct from each other, and yet in plain view.

The switch-board is small and contains only two three-plug switches for each circuit. The arrangement for a single circuit is shown in the accompanying diagram, Fig 2. A plug is inserted in each of the two left hand holes and the circuit is complete. A single

extra battery and relay is connected to all the switches, as indicated for the one set; by inserting plugs in the right hand holes of any set of switches, the extra battery can be used on that particular circuit. To test the lines the solid plug is taken out of one of the left hand holes and a split plug connected with a galvanometer is introduced; this throws the current through the galvanometer, and the resulting deflection is compared with a standard. A plug connected with ground is then inserted successively in each upper hole; a change in the deflection of the needle indicates the presence of an accidental ground connected with the circuit. No more tests are required; these simple ones, however, are repeated three times a day. The galvanometer is small, its needle being only about an inch long.

The out-door circuits, like those in the office, are metallic throughout; they consist of copper wire insulated; lightning arresters are used only where the lines enter the office.

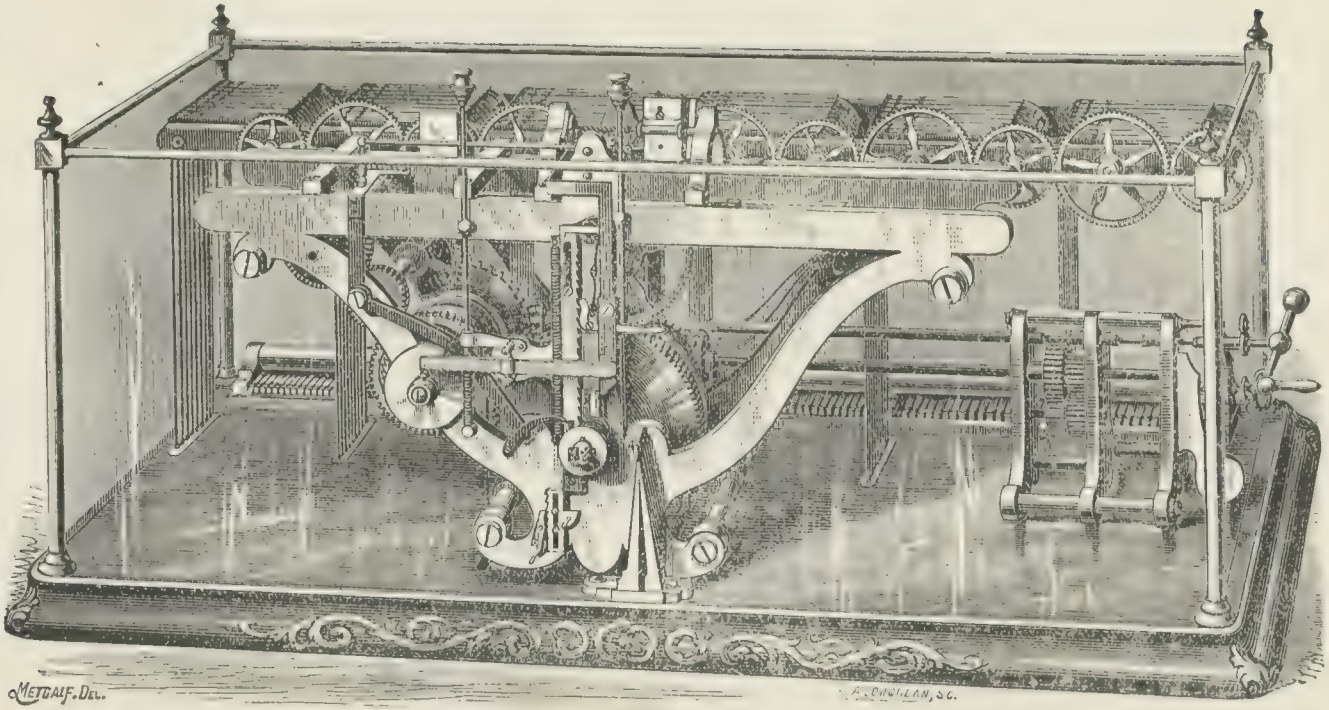
The alarm instruments contain no relay magnets; they consist of clock-work mechanism, which must occasionally be wound up. Connected with the clock-work are two circular disks, each notched upon its circumference and each pressed by a spring; the two disks are connected electrically with each other and the two springs are connected to the two ends of the circuit. When either disc turns the circuit is broken every time the spring is passed by a notch; one of the outer buttons releases one spring, the other button frees the other; the clock-work is arranged to turn either disk that is released; the disks are notched so as to produce any number desired.

The office visited was connected by seven circuits with about five hundred buildings. The signals were received by four Morse registers worked by relays. An extra register was kept in connection with the extra relay and battery for any case of necessity. The Morse registers were of the ordinary pattern except that they were furnished with an automatic movement for starting and stopping the motion of the paper upon which the signals were received. This arrangement is quite simple. The axis of the fly-wheel projects out beyond the frame of the instrument and carries a cylindrical drum upon the surface of which is cut a spiral groove; this groove runs outwards in both directions from a projecting pin placed at the centre of the drum. Connected to the arm of the recording style by a vertical axis is another arm ending in a guide which runs in the groove of the drum and which is ordinarily in contact with the projecting pin. When the armature is attracted, raising the style, this arm is also raised, the guide is lifted from the groove and a spring pulls it horizontally against the frame of the instrument. This releases the fly-wheel, the clock-work commences to move and runs out the paper. When the style falls the guide falls with it, drops into the spiral groove, and, as the drum turns, is carried out from the frame of the instrument until it again strikes

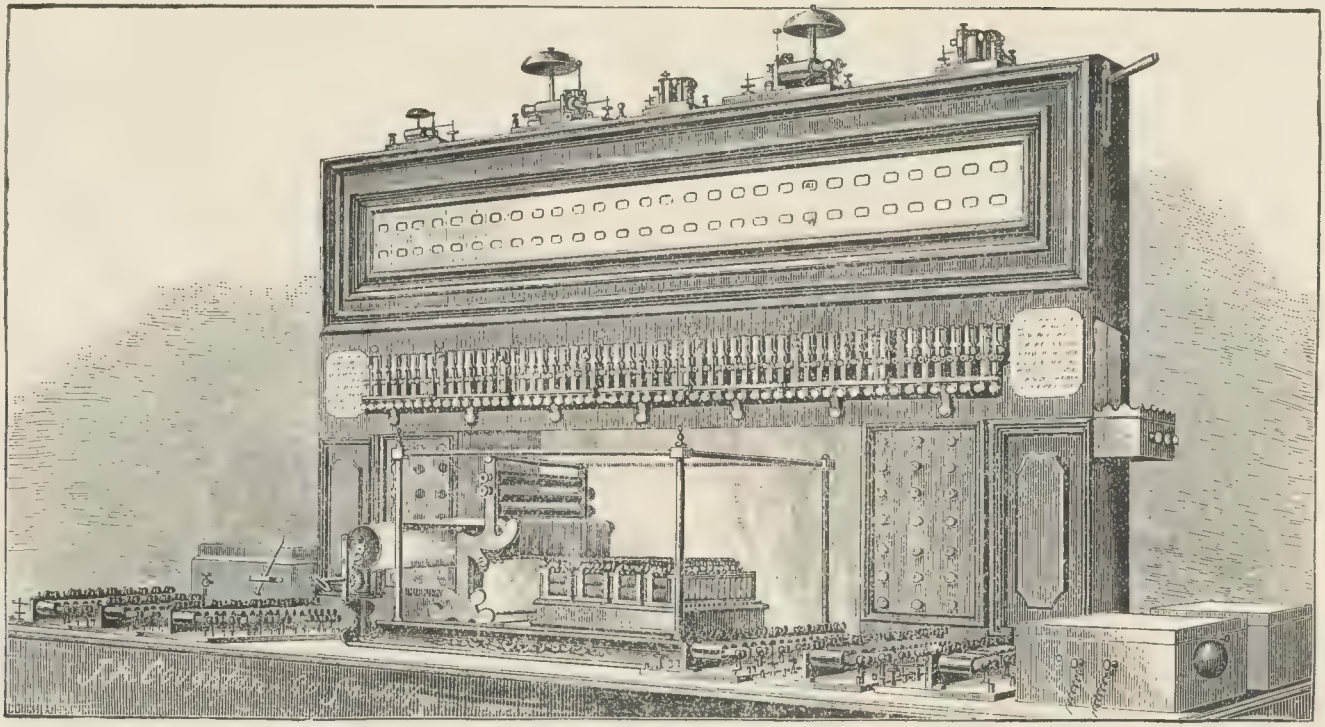
the projecting pin of the drum, stopping the motion of the fly-wheel; if the guide should accidentally jump over the pin it will be brought back there again by the reverse spiral on the other half of the drum. The stopping of the fly-wheel of course stops the movement of the other wheels and the paper ceases to run out.

The above are all the parts of the District Telegraph System which it was deemed necessary to describe.

In concluding I would acknowledge my indebtedness to Supt. C. K. Smith, of the Fire-alarm Department, for his courteousness and general attention while under his hands. A portion of his report of a previous year has been occasionally referred to in writing the above description. I am also indebted to Mr. T. J. Mc Ginty, one of the chief operators at the central office, for information upon various points, both as to the arrangement of the apparatus and to the methods of testing and carrying on repairs; also, to Mr. Chas. T. Chester, for the use of electrotype plates from which were struck off the cuts of the register and transmitter.



REPEATER OR TRANSMITTER.



THE REGISTER OR RECEIVING INSTRUMENT.

Switch Board Connections.

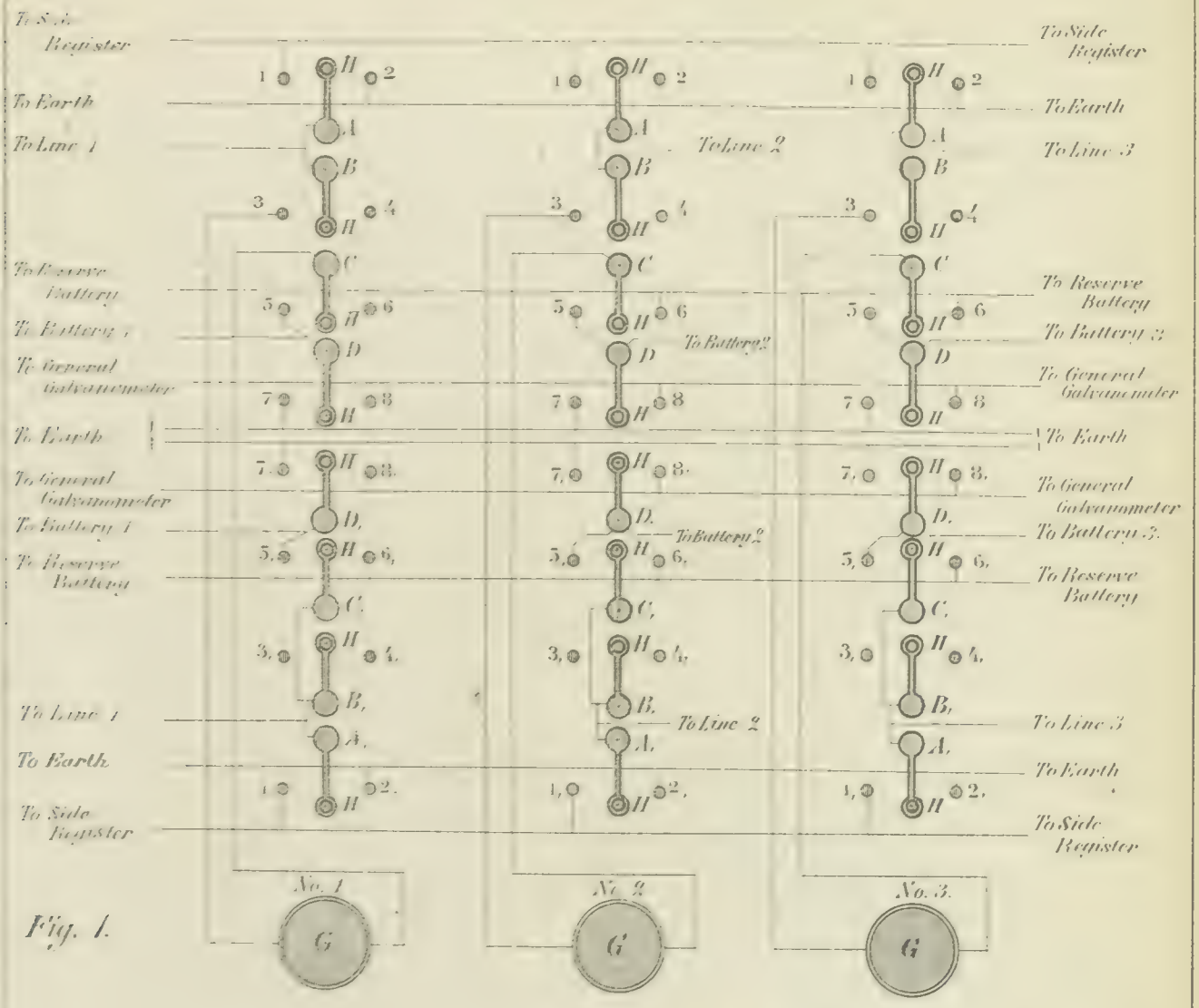


Fig. 1.

Fig. 1. N. Y. Fire Alarm System

A B C D &c.	Switches turning on A B &c as pivots
H H H	Handles of Switches
1 2 3 4 &c.	Metallic Buttons.
G G G	Galvanometers

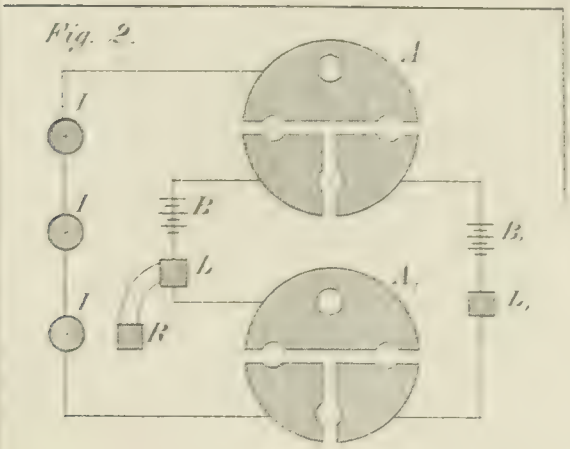


Fig. 2. District Telegraph System

A A,	Plug Switches.
1 1 1	Call Alarm Boxes and Line.
B B	Batteries.
L L	Relays
R	Morse Register.

The fine lines of both Figs show connections.

Engraved in the Office of the Board of Engineers

NOTES

ON

THE CHROMIUM BATTERY.

READ BEFORE THE ESSAYONS CLUB OF THE CORPS OF ENGINEERS,

MARCH 2, 1874;

BY

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NOTE.

This paper was prepared in compliance with instructions issued from the Headquarters of the Battalion of Engineers—under approval and direction of the Hon. Secretary of War and the Chief of Engineers—directing each officer of the Battalion to visit and examine, during the winter suspension of drills, some specified public work or manufacturing establishment. By request it was read before the Club; and being considered to contain information of interest to Engineer officers, it was ordered to be printed.

This note is prefixed by a vote of the Club, in order to explain the peculiar character, and necessarily limited scope of the paper.

BEARDSLEE'S CHROMIUM WORKS AND VOLTAIC BATTERY.

A paper read before the "ESSAYONS CLUB" of the Corps of Engineers, on March 2nd, 1874, by Lieutenant W. T. Rossell, Corps of Engineers.

Mr. G. W. Beardslee, manufacturer of voltaic batteries, military telegraphing machines, etc., occupies a large three-story brick building, No. 122 Plymouth street, Brooklyn, but only temporarily. His business at present is very small, his son and himself doing all the work.

The lower floor of their building is all that is used by them at present; it consists of four rooms. One is used as an office and testing room; another as a storage room; a third containing two furnaces—one a reverbatory furnace—and a rolling machine similar to a clothes-wringer, as a work room; and the fourth, a small room partitioned off from this last, as a labratory.

VOLTAIC BATTERY.

Captain Beardslee holds a patent for the use of chromium as the negative element in a battery, and this patent is so worded as to cover all cases, whether the metal be used alone or in connection with some other substance.

When this patent was obtained by Mr. B., he supposed that he could obtain plates of the metal by deposition, using a powerful voltaic battery. This however was found impracticable; and as the method followed by chemists would make the batteries too expensive ever to come into general use, Mr. Beardslee after experimenting some time discovered a cheap method of reduction from the chrome-iron ore. He has not applied for a patent for this, preferring to keep it secret, so that I was unable to gain any information on this point.

The metal as obtained was found too brittle to be used alone for plates. In order to obviate this difficulty an alloy of iron and chromium in equal parts was used, but the acid attacking the iron soon destroyed the plates. Lead plates were then made and the chromium pulverized was pressed on the surface of the lead. This was found to answer very well. The chromium first used contained so much iron as to give trouble;

Mr. Beardslee now boils the pulverized metal in sulphuric acid for about ten hours, to free it as far as possible from the iron. No tests have yet been made to determine the purity of the metal thus treated.

The chromium powder, examined under the microscope, consists of crystals beautifully formed, which, under pressure, fasten themselves securely to lead.

It is claimed for this battery, not only that it gives a large quantity of electricity, but that it remains constant.

The chromium being fastened on the lead plates in the form of small crystals, the hydrogen is thus allowed to escape from points mechanically. It is also claimed that the metal repels the gas and by these two means prevents to a great extent, polarization.

Several batteries were kindly set up for me, and in action the gas was thrown off with great rapidity, and tests made at the Torpedo School show that the battery is very constant.

The exciting liquid used is dilute sulphuric acid from $\frac{1}{8}$ to $\frac{1}{10}$. This gives good results; better, in fact, than the bichromate solution, which deteriorates rapidly. The last improvement of Mr. Beardslee is upon the shape of the plates.

By this new arrangement, a drawing of which is shown in Plate I., it is claimed nearly double the quantity of electricity, for the same surface, is obtained as with the flat plates.

In the cell shown in the diagram two zinc plates are used in the form of gridirons; a flat chromium lead plate is placed between these, with wings from each side passing between the legs of the zinc plates. I saw some batteries set up in this way. They formed very powerful batteries in a compact and convenient form. The smaller batteries of this kind are made with but one positive plate per cell, the wings on the negative plate extending from one side only. I think the increase in quantity in these batteries is probably due to a decrease in the internal resistance.

An experiment made by Mr. Beardslee shows that this form of plates gives a greater quantity of electricity than the flat plates; and that this increase is due to a considerable extent to the apertures made in the plates. He took about a dozen pairs of plates attached to a suitable wooden frame and immersed them in an exciting liquid, measuring the current; he then cut a strip from each plate through the centre from top to bottom, again immersed them, and found that the current had greatly increased. This result was not obtained, however, with a single pair of plates—probably due to want of delicacy in his instruments.

Traced curves were shown me giving the quantity of electricity obtained from the ordinary parallel plates and from plates of the new form. Although the conditions were

not the same in both cases, these curves show an advantage in favor of the latter.

METALLURGY.

As Mr. Beardslee's method of obtaining chromium was kept secret, my inquiries on metallurgy elicited nothing very interesting. I was shown pieces of chromium and manganese reduced by Mr. Beardslee's method. He proposes to supply them to iron works that they may be added to the ore in any quantity desired, thus always insuring good results.

I saw several pieces of steel to which chromium had been added in this way; their tone was good and the grain regular, although not very fine.

By adding chromium to brass in different proportions, it may be made to pass through various grades of strength, and its properties of brittleness and tenacity to vary between wide limits. By the presence of manganese he has obtained an alloy of brass and iron which has immense strength and tenacity. This, I believe has been done before; a piece of this alloy, I am told, being now at West Point, N. Y.

After reading this paper before the Essayons Club of the Engineer Corps, I was requested to compile the results of such experiments as had been made at the Torpedo School on the Beardslee battery, and also determine what advantage, if any, the new form of the battery possesses over the old.

I find that in April, 1873, a series of experiments were made by Capt. Mackenzie and Lieut. Price of the Engineer Corps, on the quantity of electricity obtained from different batteries. In all of these the exciting liquid was dilute sulphuric acid $\frac{1}{8}$, and the plates were of the same size $8'' \times 3''$. The positive plate in each was zinc well amalgamated. The negative plates used were:—

In Battery No.	1	Platinum polished.
"	" 2	Coke.
"	" 3	Chromium and lead. (Beardslee.)
"	" 4	Chromium and iron 50 per cent. (Beardslee.)
"	" 5	Platinized Coke.
"	" 6	Platinized Silver.

The results of these experiments are shown in the curves, Plate II. It is seen from them that No. 6 gives the best result; but this plate is objectionable, as it constantly requires to be replatinized—the platinum being carried off in minute particles as the current passes. Nos. 3, 4 and 5 came next on the list, giving almost the same quantity of electricity at first. No. 3 (Beardslee), although the lowest at the start, soon rises, and at the end of fifteen minutes is second only to the platinized silver, No. 6; thus showing for quantity and constancy, qualities superior to any that were tested.

For these experiments a Gaugain tangent galvanometer was used. The veber coef-

ficient of this instrument having been determined by the following method; by means of a Thompson reflecting galvanometer and a condenser the electro-motive force of several batteries was found by comparison with a Clark's constant battery; the deflection on the tangent galvanometer caused by the battery in the intervals of discharging the condenser, was also carefully noted. Thus: condenser charged for 30 seconds; then discharged through reflecting galvanometer—during this last period current from battery passing through tangent galvanometer; charge condenser again for 30 seconds, and so on. The internal and external resistance was also carefully measured—these from Ohm's law.

$$Q = x\,t = \frac{E}{R+r}: \qquad x = \frac{E}{t(R+r)}$$

x = veber coefficient.
t = tangent of deflection.
E = electro-motive force.
R = resistance of connections.
r = internal resistances.

More than 200 observations were taken with E and R varying, and from them x was determined very closely.

In February, 1874, I find that two batteries, one of zinc and coke and the other Beardslee old style, were compared. The plates used were $7\frac{1}{2}'' \times 4\frac{1}{2}''$, and the results obtained are shown in the curves No. 7 and 8, these corroberating the former results.

In both of these sets of experiments the first reading was taken as soon as the needle came to rest, which was between 15 and 30 seconds after the current commenced flowing, in every case; the second reading after the battery had been in action one minute, and then at intervals of 30 seconds. To determine whether or no the new style of battery possessed any advantages over the old, the following* was found from careful measurement with a cell of each style—there being in each exactly 104.4 square inches exposed surface of lead and chromium, in dilute sulphuric acid, and the plates being separated exactly half an inch.

The fall of electro-motive force in new style before circuit was closed, is probably due to the want of proper insulation between the two plates in the cell, slightly polarizing the battery. The insulator used is wood parafined.

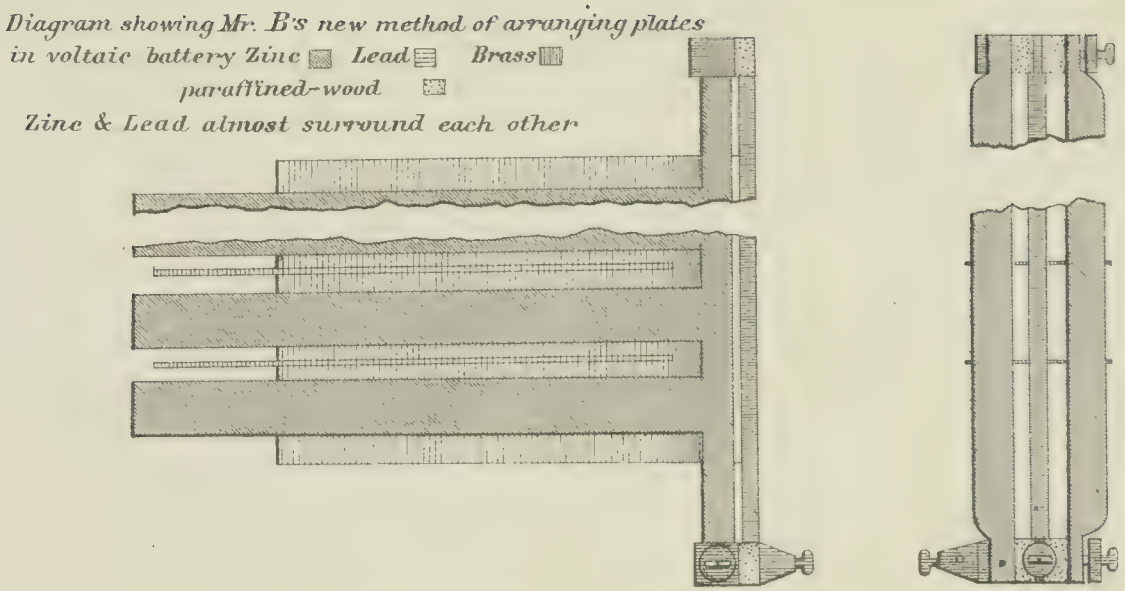
Measurements were taken once a minute, the first one 15 seconds after switching on the battery. The results are the means of eight measurements. These are the principal measurements taken, and show a decided advantage in favor of the new style. This is due, first, to a decrease in the internal resistance; second, to an increase in the electro-motive force.

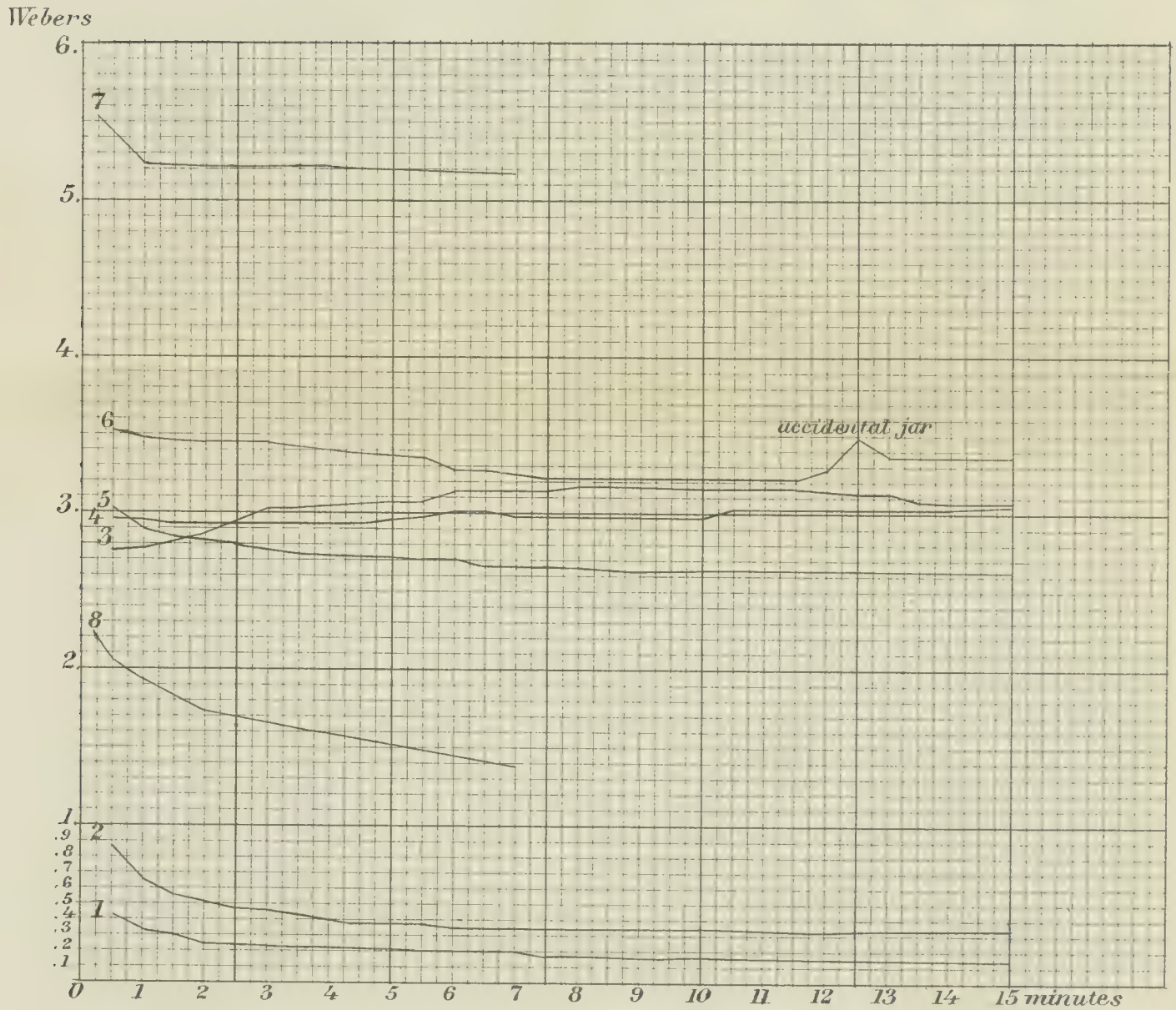
* See Table, page 62.

The decrease in the internal resistance is due, probably, to the ease with which the liquid can flow in almost any direction through the apertures in the zinc plates, thus aiding the escape of the gas mechanically. The increase in the E. M. F., I cannot account for, unless there was some superiority in the plates used in this battery over those in the old style cell. In the measurements made it was also found that in this new battery the E. M. F. and the quantity was constant for any given circuit.

Thus, allow the battery to work on a circuit of 100 ohms, these two elements are constant; now if the battery be worked on a circuit of .5 ohms and immediately after returned to a circuit of 100 ohms, the E. M. F. and quantity will also immediately return to what they were before on this circuit.

Ohms in Circuit.	New Style.			Old Style.		
	Int. Res.	Volts.	Vebers.	Int. Res.	Volts.	Vebers.
Not closed.	ohms. .0148	.975 falling in about 10' to .790		ohms. .0198	1.115	
136	"	.856	.0062	"	.681	.0050
116	"	.806	.0070	"	.653	.0056
96	"	.751	.0078	"	.641	.0067
76	"	.681	.0090	"	.633	.0083
56	"	.638	.0114	"	.623	.0112
45.93	"	.619	.0137	"	.617	.0135
0.75	"	.490	.616	"	.480	.616
0.068	"	——	7.926	"	.508	7.476


Diagram showing Mr. B's new method of arranging plates
in voltaic battery Zinc Lead Brass
paraffined-wood
Zinc & Lead almost surround each other


Webers
6.
5.
4.
3.
2.
1
.9
.8
.7
.6
.5
.4
.3
.2
.1
7
6
5
4
3
8
2
1
accidental jar
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 minutes

LITHOGRAPHIC

AND

PHOTO-LITHOGRAPHIC WORKS.

READ BEFORE THE ESSAYONS CLUB OF THE CORPS OF ENGINEERS,

APRIL 3, 1874;

BY

LIEUT. JAMES MERCUR,
CORPS OF ENGINEERS.

NO. XXXI. PRINTED PAPERS.

Printed on the Battalion Press.
Sergt. Carmichael & Pvt. Redfield, Printers.

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NEW YORK LITHOGRAPHING, ENGRAVING AND PRINTING CO.

A paper read before the "ESSAYONS CLUB" of the Corps of Engineers, on April 3rd, 1874, by Lieutenant James Mercur, Corps of Engineers.

The "New York Lithographing, Engraving and Printing Company," of which Mr. Julius Bien is Superintendent, occupies the upper four floors of the five story building No. 16 Park Place. These floors have each about twenty-five hundred square feet area, and are occupied as follows, viz. :—

The second floor is divided into three parts, of which one is about as large as the other two, and serves as a ware-room in which the finished prints are placed for counting, inspection and packing. The other two parts are respectively offices for the Superintendent, book-keeper, etc., and a room occupied by the engravers and draughtsmen of the Company.

The third floor is used by the engravers on stone and printers; the fourth by the transferers and printers; and the fifth by the photographers and engravers on copper.

The processes, principally used in this establishment are, common lithography, engraving on stone, and photo-lithography. Subordinate to these are engraving on copper and a method of photo-zincography, which is used for making a type, which may be set up in the same form with common type and printed from in the ordinary printing press.

The processes of photo-lithography, requiring a complete and very perfect photographic establishment, enables this Company to make photographs of large size and excellent quality, although this is only done as an accomodation to customers, and does not form a leading part of their business.

There is nothing secret in any of these processes; the points which differ from the older and more common methods being covered by patents taken out by Mr. Bien, who seeks to excel his numerous competitors by allowing only work of the best quality to leave his house. He tries to secure this result by the use of the best methods and materials, and by constant personal attention to all the details.

In the first, or "common lithographic method," the drawings are made upon transfer

paper, in greasy ink, and then transferred to the stone by placing the drawing upon it, face downward, and passing it through the press. By this means the greasy ink is taken up by the stone; leaving the transfer paper nearly in its original condition, while there is impressed upon the stone an inverted print of the original drawing. Assuming that the drawing upon the transfer paper is properly made, the excellence of the impression obtained by this method, must depend upon the character of the ink, stone, and press used.

The thickness of the ink, particularly, has great importance in this and all other processes of lithography, since, if two thick a coating is placed upon the paper, or if the ink be too soft, or the pressure too great, the lines will "smash" or be widened and made irregular under the press, which effect will, of course, be reproduced in the print. On the other hand, if the ink is too hard or dry, it may not be completely transferred, producing an impression in which some lines are lacking.

After the transfer is made the next process is called "preparing the stone," and since this "preparation" is what enables the stone to be printed from, a description in some detail will be given of the method used.

The transferred impression, after the paper is removed, is covered with a coating of gum water sufficiently thick to protect the surface from dust, by the film of gum left by the evaporation of the water; this gum is left on the stone until the grease in the transfer ink has been well absorbed by the stone; it is then removed by washing with water, and the stone while still damp with the gum water thus produced, is rolled over with a coating of black ink, which being repelled by the damp part of the stone and attracted by the parts covered with grease, serves simply to thicken the ink on the impression already made; a coating of resin is then given to this ink by dusting it over with finely powdered resin, which adhering to the ink, has the effect of thickening it and rendering it more able to resist the action of the dilute nitric or hydrochloric acid, with which the surface of the stone is next covered.

This coating of acid is not of sufficient strength, nor applied long enough to sensibly depress the surface of the stone not covered with ink, nor is it designed for this purpose, but only to change the character of the surface, possibly by leaving a small portion of a lime salt, but more probably by simply rendering it slightly rough, so that it will the longer retain water when dampened.

After the application of the acid, the stone is washed clean and the thick coating of ink removed by the use of spirits of turpentine, leaving the original design upon the stone in grease only, and only visible by close inspection.

If not wanted for immediate use, the stone is now covered with a coating of gum,

as before, to protect it, but if desired it may be used immediately for printing, being careful to dampen it thoroughly with water containing a very little gum in solution, before applying the ink.

In printing, the stone is placed in the press, which is carefully adjusted so as to avoid, as far as possible, danger of breaking it; the surface is carefully dampened and the ink is applied with a roller. This ink is, as before, repelled by the moist part of the stone, and attracted by the greasy part, so that it "takes" only on the impression and leaves the white parts entirely free.

The paper is now placed upon the stone and the two together drawn through the press; under the pressure the ink is taken up by the paper which thus becomes a lithographic print.

The character of the printing ink here needs the same careful watching as did the transfer ink before, to avoid "smashing," on the one hand from being to soft, and on the other, it must not be so hard as to require pressure sufficient to endanger the stone, in order to secure a good impression.

In all the different methods of lithography the printing is essentially the same, and since there are so many precautions necessary which can only be learned by experience, it is evident, that the best quality of work can only be done by those who have had large practice, and who are very careful in the manipulation of stones, ink, and press.

This general method of lithography is largely used in printing maps which have been engraved on copper plates, in order to save the wear which the plate itself would undergo in the press. In this work the transfer sheet is printed directly from the copper-plate, in the usual way, except that transfer ink is used instead of common printing ink. Frequently, also, one good impression of a map or other subject having been obtained upon a stone, this stone is used in the same way as the copper-plate, to supply transfer sheets, which are used to prepare stones for printing; the original being thus secure from the danger of breaking in the printing press. Formerly, the plan of drawing directly upon the stone with greasy ink was much used, but as this requires the drawing to be inverted, and has no particular advantage over the transfer method, it is now very little used.

PHOTO–LITHOGRAPHY.

All the different processes which have been devised for printing in permanent pigments from photographic negatives or positives, depend upon the fact that, if a certain quantity of an alkaline bichromate be dissolved in a solution of gelatine, which is then allowed to dry and is exposed to the action of light, the parts acted upon by the light become insoluble in water, while those not thus acted upon will, when placed in water,

swell up and dissolve like pure gelatine. This principle is thus used in the process which Mr. Bien employs, and which is a modification of what is generally known as the "Osborne Process." By the ordinary photographic processes and the use of the best lenses, such as the Dallmeyer, the Harrison and Schnitzer Globe, etc., negatives free from distortion, of great intensity, and most perfect sharpness of definition are obtained.

A fine quality of plain photographic paper is sensitized by coating it with a solution of gelatine, permanganate of potassa and bichromate of ammonia; this is then dried in non-actinic light, and exposed under a negative for a time varying from fifteen seconds to as many minutes, the action being more rapid when the film is warm, other circumstances being the same. The proper exposure is known by experience, as in photography, but may be determined by exposing a piece of paper similarly sensitized, beside the printing frame, until it assumes the color indicative of sufficient action. Having been thus exposed, the paper is removed and without being exposed to light, is covered on the gelatine side with transfer ink, by laying it face downward upon a plate coated with ink and passing it through a press. The paper is then floated and washed in warm water, which removes the surface of the unaltered gelatine together with the sensitizing material which it contains, and the ink which adheres to it, and leaves the print upon the paper in transfer ink.

This print, being thoroughly dried, is then transferred to the stone in a manner entirely similar to that used in common lithography; but as only the ink is removed, the paper might be recharged and used a second and third time if necessary, since it is only requisite to moisten the surface of the gelatine, to make it act toward the transfer ink in a manner similar to that of a prepared stone; *i. e.* it will "take" the ink on the insoluble parts and repel it from the unaltered. Mr. Bien has patents also upon a method of photo-lithography, in which the stone receives a preparation which renders it sensitive to the action of light, in which condition it is exposed under a "positive" prepared either by printing from a negative or by the use of a camera, by removing and reversing the film of the common glass negative. The first method appears to be principally used by him, although I am informed that he sometimes uses the second.

ENGRAVING ON STONE.

This process, by which all the finest line work is done, is conducted as follows:— The stone, having a finely polished surface, is covered with what is called an etching color, which is composed of a mixture of solution of gum arabic and lampblack or red chalk; this being allowed to dry on the stone becomes of an opaque black or red color, and is impervious to greasy ink. The engraver by the use of steel needles of different degrees of fineness, and diamond points, cuts away the etching color in a manner similar

to that followed by an engraver on copper or steel, except that no effort is made to cut deep lines; in fact they are avoided, and the needle only removes the etching color, and this, when practicable, by a single stroke; any errors being corrected or alterations made at any time before the stone is finished, by covering with a new coating the marks to be erased.

Frequently in this process it is desirable to obtain different shades of the same color, upon different parts of the print, as in geological charts, etc. In such cases many engravers on stone proceed as follows:—

After the engraving with the needle is completed, that part of the stone which is to give the lightest shade is protected, and the rest subjected to the action of weak acid. After a short time the next lighter shade is also protected, and a second dose of acid given to the stone; and this process is repeated, protecting new parts each time, until the stone is completed. When this is used, however, a different etching color, which is impervious to acids and which is called an etching ground, is employed to cover the stone. This method is not used by Mr. Bien, as it gives to the lines a certain irregularity of outline and thus interferes seriously with the finish and excellence of the work. The same effect of shades with clearness of lines, is obtained by making with the needle the shading lines more or less near together, and wider or narrower according to the result desired.

When the engraving is completed the whole is covered with greasy ink which, of course, only "takes" upon the parts exposed by the action of the needle. The etching color is then washed off and the stone prepared for printing as in the other cases.

THE ZINCOGRAPH.

This is the only process employed by Mr. Bien in which etching is generally used. In this the impression is made upon the zinc in the same manner as in the photo-lithograph; by a patented process, the zinc having been exposed to an etching acid, is so protected that the acid does not eat under the parts to be left in relief; thus making a strong type for use in the common printing press without fear of its being broken down under the pressure. The etching is made deep enough to give a good relief to all the surface, and any large whites are then cut out by a revolving tool somewhat like a drill having a square end. Holes are then made in the zinc plate, and it is attached to a wooden block of sufficient thickness to bring it to the proper height to work with common type.

From the general outlines of the processes employed, it will be seen that they are nearly the same as those used in all similar establishments, but as Mr. Bien has kindly

given me some of the details of his processes; they may, in part, explain the high character of the work done by him.

STONES.

The lithographic stones are all limestones, nearly pure carbonate of lime; those used by Mr. Bien are all obtained along the Danube in Bavaria, and principally from the quarries of Solenhofen, not far from Munich; but stones of fair quality are found in Italy, England, France, Russia, and in Kentucky in the United States. For some work pure marbles will answer very well.

In thickness the smaller stones should not be less than one and a half inches, and the large ones from two to four. The harder stones, with a slightly bluish tinge, are generally best, if they are free from white spots; the softer ones have generally a more distinctly marked yellow color.

The stones, after being quarried, are ground to plane surfaces and polished; this is done by rubbing the elevations with sand or pumice stone until a straight edge will lie smoothly along the stone, which is then placed on a horizontal table with a small quantity of fine wet sand upon it. Another stone is placed face downward upon this, and rubbed in different directions, with occasional renewal of sand, until the surfaces are polished smooth, and are as nearly plane as it is possible to make them. This seems to be the best method, whatever use is to be made of the stone afterward. The last polishing is done without changing the sand for a long time, by which it, being ground to a fine dust, leaves a smooth surface such as is required for line drawings and engravings.

For anything like imitations of crayon drawings the polished surface receives a "grain," by regrinding it with sand of a silicious nature, and round grain of the coarseness necessary to give the required surface, care being taken to cause the stones to move in a great many different directions to avoid the formation of furrows.

Various substitutes for stone have been tried, but with rather limited success for the finer kinds of work, but for coarser work, zinc plates prepared like the stones, but with different acids and slightly different inks, work very well.

INKS.

The inks used in lithography may be divided into two general classes, viz.: 1st, the greasy or Transfer inks; 2nd, the Printing inks.

The greasy ink, although varying in its composition to suit different kinds of work, still in all cases consists essentially of a grease, like oil or tallow, a coloring matter like lampblack, and a resin of some kind to give it body.

The essential part is the grease, which by penetrating the stone gives it the property

of repelling water and attracting the printing ink. The coloring matter is used to show the places on the transfer paper and stone upon which the ink has taken, and thus make known the character of the impression and the presence of any erroneous markings; but having accomplished this object it is all removed from the stone before the printing ink is used.

The black printing ink consists principally of boiled linseed oil and lampblack, with the addition of various substances designed to fit it for the particular work in which it is to be used. Both these inks are imported by Mr. Bien, and made thick or thin, hard or soft, according to the temperature of the printing room and the character of the lines in the print. The printing ink is toned to suit the color of the paper, by adding to it a little of some pigment complimentary to the color of the paper: *e. g.*, if the paper has a yellow tinge, and a clear, sharply defined line which will contrast strongly with it, is wanted, a little blue is added to the ink; but if soft effects are sought, the ink is toned by the addition of the proper colors to produce them.

The colored inks used are all prepared under Mr. Bien's supervision, and are modified to produce with each other, and with the paper used, the most pleasing effects.

PAPER.

A great variety of paper is used, being carefully selected in each case to suit the particular work for which it is required. For most purposes, and in those cases in which the print can all be taken on a single sheet, damp paper may be used, which gives an opportunity to select paper with a surface proper for producing effects similar to crayon drawings, water colors, etc., etc., but in maps made up of several sheets which are to be joined together after printing, damp paper would stretch unequally and not admit of accurate joining in the details. In such cases the printing is done on dry paper, which in order to take a good impression is heavily calendered, and sometimes also pressed between plates, giving a hard, smooth finish. If these sheets are large they are calendered in the same direction as that in which they go through the printing press, to avoid any stretching in the printing.

PRESSES.

For the finer work, hand presses of what is known as the scraper pattern are used, since they allow the printer to examine the stone before each impression, and to ink more or less heavily on special parts, to produce the best effects possible. But in all common work of which a large number of copies are wanted, the steam press is employed as being more economical. In the use of the steam press, however, the oportunity for minute inspection before printing each copy is lost.

The stone, having been once properly prepared, can be used to print in any color, or can, after having been used to print in one color, be used for another, with no other preparation than cleaning off with turpentine the ink remaining after the last impression, before using the color. When two or more colors are used on the same print, a separate stone is needed for each color. This necessitates keeping a very accurate register, particularly in fine work. The following method is used :—

The stone giving the general outlines is charged with *printing* ink, a print taken, and this print before becoming dry is used as a transfer sheet, and one impression made on a second stone. Upon this is made in greasy ink the part of the original design which is to take a certain color. The black printing ink can then be removed with turpentine, and the stone prepared for printing. Corresponding stones are prepared for each of the other colors. Upon each of these stones are carefully marked two or more points, which were selected upon the original stone and transferred to each of the others. A very fine needle hole is drilled in each of these.

The imprint from the first stone is carefully punctured with needles in the selected points, and the printer putting a needle in each of these punctures, places one in its corresponding hole bored in the stone, and using this as a centre, moves his paper until the second needle reaches the second hole ; the paper then lies flat upon the stone and the register is perfect.

The use of so many stones, requiring so much more time and labor, necessarily makes the use of many colors very expensive ; but by a judicious combination of different shades of the same color, and by printing one color over another, using inks sufficiently transparent to combine in this way, the expense may be very much reduced. A specimen of work was shown by Mr. Bien, in which by the use of simply red, blue and buff, he had obtained eleven distinct shades ; these, with two from the original black, gave thirteen distinct shades by the use of but four stones, and consequently by passing the print through the press but four times.

From the description of the different processes it becomes evident that they are not equally applicable to all kinds of work. The photo-lithographic needs, as before said, sharply defined and very intense negatives ; these can only be obtained from line drawings which are made on paper of good tone. Anything which is drawn in colors which do not photograph well, or which is shaded in flat tints will not produce negatives which are entirely transparent in the lines and sufficiently opaque in the whites, consequently the prints must be unsatisfactory.

The results obtained by this method are always better when the drawing is reduced somewhat from the original. But in all cases to which it is applicable the photo-lithographic is the most rapid and cheapest process, while it produces work of excellent character. As an example of the rapidity with which it may be used, Mr. Bien states that, in an emergency and with all circumstances favorable, a photo-lithographic print could be produced in from two to three hours after the receipt of the original; but as this speed requires everything to be subordinate to it, it would never be attempted except under very peculiar circumstances. The ordinary lithographic process is principally applied to printing from stones, matter already engraved on copper, steel, or stone, and the coarser sorts of drawings which can be readily made on transfer paper, or on the stone directly; thus giving it an extended use in copying, but a comparatively limited one in producing originals. For the finest work done in the establishment the process of engraving on stone is used: this is necessarily the slowest and most expensive of all, but has the advantage of allowing very careful supervision in all the details of the work, in being susceptible of application to all kinds of drawings, and in admitting of the production of a finish in its products, which can with difficulty be distinguished from the finest copper-plate engravings. Some excellent specimens of this work may be seen in Mr. Clarence King's Report on the Geological Survey of the Fortieth Parallel, particularly in the fifth volume.

The zincograph process does not seem to be fitted for the production of fine work, but having the advantage of giving metal plates which can be printed from in the same form with common type, it is useful for many purposes, particularly for illustrating school geographies, geometrics, works on physics, etc., etc.

In conclusion, I am glad to have an opportunity in this paper to express my thanks to Mr. Bien for his courtesy in explaining to me the processes used by him, and for the opportunities given to me for inspecting his establishment.

NOTES

ON THE

CONTINENTAL IRON WORKS.

READ BEFORE THE ESSAYONS CLUB OF THE CORPS OF ENGINEERS,

APRIL 3, 1874;

BY

LIEUT. HENRY S. TABER,
CORPS OF ENGINEERS.

NO. XXXII. PRINTED PAPERS.

Printed on the Battalion Press.
Sergt. Carmichael & Pvt. Redfield, Printers.

NOTE.

This paper was prepared in compliance with instructions issued from the Headquarters of the Battalion of Engineers—under approval and direction of the Hon. Secretary of War and the Chief of Engineers—directing each officer of the Battalion to visit and examine, during the winter suspension of drills, some specified public work or manufacturing establishment. By request it was read before the Club; and being considered to contain information of interest to Engineer officers, it was ordered to be printed.

This note is prefixed by a vote of the Club, in order to explain the peculiar character, and necessarily limited scope of the paper.

THE CONTINENTAL IRON WORKS OF BROOKLYN, N. Y.

A paper read before the "ESSAYONS CLUB" of the Corps of Engineers, on April 3rd, 1874, by Lieutenant Henry S. Taber, Corps of Engineers.

The Continental Iron Works, situated at Green Point in the northern part of Brooklyn, occupy sixty-two lots, or one block; bounded on the east, north, south, and west sides respectively, by West, Calyer and Quay streets, and the East river,—having a water front of over two hundred feet.

In addition to the property thus bounded, there are several lots, on the opposite sides of the bounding streets, occupied by one *machine shop*, a *pattern store-room*, the stables, and as general storage ground for castings, boilers, complete or in process of construction; so that the space, *in toto*, covered by the works, is over four acres. Exclusive of the *pattern store-room*, three buildings, subdivided to suit the business conducted, and arranged with reference to the successive steps of manufacture, constitute the structures of the Company. The foundry and one engine building are of brick, the remaining buildings are wooden.

The office, foundry and mould-loft occupy one building, fronting on West, and extending 320′ along Calyer street. Size of office, 10′ to 15′ × 50′; of foundry, 125′ × 75′; and the *mould-loft*, 180′ × 50′. The longest building stands on the southeast corner of the block.

The third building, 150′ × 50′ in size, standing diagonally opposite the foundry, *across Calyer street*, is the new machine shop.

Both cast and wrought iron are manipulated by the Company; but the former only is manufactured at the works, the latter being ordered as required for the various uses to which the Company's machinery permits its application.

Cast iron is made from old pieces of iron, such as broken castings, shafting, etc., mixed with due proportions of coal. The manufacture of castings from this material is divided into five processes. 1st, The preparation of the pattern; 2nd, Same of the

moulds; 3rd, Melting the iron; 4th, Casting; 5th, Cleaning and finishing. The Company have all requisite buildings, foremen, etc., etc., necessary to conduct the work in all these stages.

The pattern shop, 80′ × 48′, used for preparing the patterns, is provided with ordinary turning lathes, saws (jig, circular and endless), carpenters' benches, glue pots, and other suitable tools for constructing the patterns from the drawings sent from the drawing-office. The upright or jig saw, is peculiar in being driven by two horizontal shafts instead of one, so connected as to regulate each other's movements—the upward movement of the saw being as strong and steady as the downward. This saw is used for cutting curved surfaces, the curvature being regulated by moving the piece by hand. The endless saw consists of a combination of wheel-work, so arranged as to carry a band of steel, one edge of which is cut with saw teeth. This band passes around two large wheels, one above and one below the working table, and perpendicular to it. Bands of various weights are kept, having coarse and fine saws for edges, adapted to coarse or fine work.

The glue is kept constantly hot by sitting the glue pots in a covered trough into which a steam pipe is led. The core patterns are painted black to distinguish them, the others are generally not painted, receiving a coat of varnish instead.

The foundry, 125′ × 75′, built of brick, has a roof peculiarly trussed and braced, to resist the varying strains brought upon it by the powerful cranes, hereafter described.

Extending the entire length of the building, and 50′ in width, is the space occupied by the moulds, either in boxes sitting on the surface, or packed in the sand floor itself, as in case of large castings. Five large cranes are ranged along the central line of this portion, in relation, so that a heavy weight can be swung from end to end of the foundry by using the cranes in succession. On the other side of the building, for a distance of about 46′ from each end, there are two additional spaces that may be used as moulding ground. One of them is at present used as a general storage ground. The balance of the building is occupied by the cupulos, engine room, and core ovens.

The cupulos stand in a recess, open to the exterior, 25′ × 25′. Next to this is the engine-room, then a large core oven, 12′ × 25′; next a free space, then two small core ovens and a second large one. Two cupulos are used for melting the iron, one being McKenzie's patent cupulo, the other made after the Company's model. Both are of the same height from ground to top of chimney, *i. e.*, 50′; also have the firing door at 14′ from the ground. The Company's rests on four pillars 3′ 6″ in height, and is lined with fire-bricks 9″ in thickness to a height of 15′ 6″ above its base, leaving a free space 4′ in diameter on the interior. This cupulo is circular in horizontal cross-section, and has a cylindrical chimney 5′ 6″ in diameter.

The patent cupulo, ellipsoidal in horizontal cross-section, rests on four pillars 4′ in height, and for 2′ 6″ above the base, the lined portion is somewhat smaller than above, where it is 7′ 3″ in transverse, and 4′ 6″ in conjugate diameter. The lining rises to the height of 12′ 6″ above the base, and terminates in a cone-shaped top which receives the cylindrical chimney, 4′ 6″ in diameter. Each cupulo has *tuyere* pipes for cold blast, and conduits for drawing off the melted metal. The blast is produced by one of Sturtevant's blowers, driven by a 30-horse-power engine, whose shell diameter is 3′ 6″, and length 8′ 6″, with a steam drum 28″ in diameter and 3′ high. To fire up the McKenzie 1800 lbs. of coal are put in, then three ton of iron; 600 lbs. of coal to 6,000 lbs. of iron; and so on (the number of layers depending upon the number of castings), the blast turned on and in 15 *minutes* metal can be drawn. To fire the other, 480 lbs. of coal are first put in; then 3000 lbs. of iron; then 250 lbs. of coal and 1600 lbs. of iron, continuing as before. Thirty minutes after turning on the blast, the melted metal may be drawn. The coal or iron in either case is raised to the firing door by a 14′ hydraulic lift, enabling one man to fire the cupulo. He has only to weigh out the coal, or the iron, load the table as it lies in the surface of the ground, move a lever which starts a pump worked by a pair of oscillators; ascend to the firing door and wait for his load; or may weigh out another load while it ascends. The load is stopped automatically. The base of the cylinder supporting the lift table, is 15″ in diameter. Each cupulo is provided with piercing and tamping irons, for tapping and plugging it; the former being about 8′ in length and tapered to a point; the latter having about the same length, a wooden handle, and a small circular cap $1\frac{3}{4}$″ in diameter attached to the end, which receives a coating of wet clay, and being pressed against the opening through which the metal is flowing, so chills it as to stop its flow.

Ladles of various capacities, made of iron, lined with clay, and provided with handles according to their size, are kept near the cupulos for carrying the metal to the moulds at the hour of casting. For large castings, a huge ladle is manœuvred by the cranes.

Adjacent to the engine-room is a large core oven, 12′ × 25′, heated by a reverbatory furnace, and provided with a heavy car moving upon a track out into the moulding ground where the core is prepared, placed on the car, pushed into the oven, the iron doors closed, and the core left to dry. No particular attention is paid to the temperature of any of the ovens.

An open space next this oven is devoted to mixing sand and clay for moulds and cores, and for preparing the small cores. Near this are the two small core ovens, 6′ × 12′, similar to the large one, except that one has no car. Another large oven completes the arrangements for carrying on the processes of casting.

This process varies with the patterns, but presents the following main features for ordinary work, as distinguished from loam work.

To form the moulds, jackets are provided built in sections, and having suitable appliances for effecting their union. In large cylindrical castings, where great pressure is expected, the moulds are sometimes enclosed in a self-adjusting exterior jacket made in sections from 4′ to 6′ in length by 2′ in width, and $\frac{1}{8}''$ to $\frac{1}{4}''$ in thickness, provided with hinges for junction, so made as to conform, within certain limits, to any cylindrical casting.

To prepare the mould for the reception of the metal, the lower section of the jacket is placed upon the ground, a suitable amount of sand rammed down upon the bottom, the pattern, or so much of it as may be required, set in, and sand rammed around it until this section is full. The separating sand is strewn over this; the next section of the jacket placed and the ramming performed as before; and so on until the jacket is complete; when it is removed by section, the pattern taken out, the sections carefully rejoined, the opening for the passage of the metal sprinkled with flour, and the mould is ready. For very long castings cell-like sections are used, better to hold the sand. For hollow castings a core, placed in after the pattern has been removed, is used. The pattern is made solid; and at the point at which the opening in the casting is to appear at the surface a projection is added to the pattern, so large that when the pattern is removed from the sand, the hole left will receive a projection attached to the core, and hold the latter in position. To form the core, another pattern of the exact shape interiorly of the desired hollow, is made; carefully filled with flour and sand in proportion of 1 to 6 well packed; the core thus formed taken out, removed to the core oven and dried. A projection corresponding to the hole destined to receive it, in the mould proper, is formed on the core. The core is removed after casting by breaking it in pieces. Care is taken in large castings to remove the core before the metal has cooled too much.

Large cores are prepared as the small ones, bricks being used to facilitate the preparation and strengthen the product. All cylindrical castings are by loam work.

By this method a vertical shaft, 9′ to 10′ in height, is set up. This shaft carries boards, in position parallel to itself, the distance of whose interior and exterior edges from it may be regulated at will. To form the casting, an exterior cylinder is built up of brick and loam, whose interior correspond to the exterior dimensions of the castings desired. The interior surface of this cylinder is rendered smooth and uniform by the continued revolution of the shaft, bearing at the proper distance the board whose exterior edge guides the workman.

This exterior cylinder, completed, is placed on the car and pushed into the oven.

The core is built in a similar manner, its exterior corresponding to the interior dimensions of the required casting, the workman being guided as before; and when completed this is also placed in the oven. When dry, the exterior and its core are carefully placed in proper relation, the strengthening sections placed around them, and the casting made —the core being knocked out before the casting is quite cool. After removal from the moulds the castings are taken to the cleaning shop, the adhering sand removed, projections chiseled off, and small irregularities corrected by grinding.

When a casting has a small piece broken out, the entire casting is buried in the sand, a mould of the broken part carefully made, and at some regular casting a ladle of molten metal is brought and quickly poured into the mould. The heated metal melts the main casting, so that a firm union takes place; and often several hundred dollars are saved by this process.

Boiler making and armor plating are two *important* branches of the wrought iron work of the Company: and a great variety of other work is done. The boiler shop, 150′ × 50′, is occupied by the following tools, driven by means of a 40-horse-power engine, whose shell is 10′ in length by 4′ 6″ in diameter, by means of belting through a line shaft extending the entire length of the shop,—the shaft, drive-wheel of engine, belting and secondary shafts having run three years without alteration, and still running with a very uniform motion when all the tools are in use, viz.: Two sets of rollers, one of which has two under moveable rollers 8″ in diameter, and one upper, 10″ in diameter, used for straightening or bending plates up to 6′ 4″ in width; a third pair exterior to the building is used for heavier work; one angle iron shear, used for cutting angle iron up to 1″ in thickness; one planer, capable of planing armor plates 12′ square; one sliding-tool planer—the work being stationary while the cutting-tool travels along it—with a vertical feed of 3′ or 4′; one shaping machine—a labor saving contrivance taking the place of chisels in trimming ends and short surfaces, and regarded as the most useful instrument in the shop; one bolt cutter; several vertical drills—some with screw, others with lever feed, the latter being regarded as the best; a multiple punch capable of punching from one to sixty holes per stroke, of making nineteen strokes per minute, and used in perforating plates for the gas-works; three heavy steam-punches, capable of punching plates 2″ thick; two heavy steam-shears, capable of cutting iron 1″ thick. Both the shears and the punches act by cam motion, a heavy drive-wheel being in constant revolution and its momentum locked in and transferred to the punches or shears at the option of the workman, by means of a lever. Suitable cranes are provided for handling heavy work. At present, the shop is occupied with armor-plating the decks of the monitors Catskill and Montauk.

A steam riveter, invented by Mr. Rowland, is soon to be placed in this shop. By this a rivet head will be completed at one stroke, the momentum of a large drive-wheel being utilized to produce a tremendous pressure. This machine is particularly intended for use in making boilers and tanks.

The old machine-shop, $115' \times 25'$, is nearly vacated in favor of the new. The latter contains the following tools :— One planer standing on a brick foundation with a table $25' \times 5'$, and having a height of $4\frac{1}{2}'$ under its cross-head; one large engine lathe, with a swing of $5'$ and a bed of $22'$; one double-ended lathe, with a swing of $36''$ and bed of $25'$, capable of being used as one or two lathes; one screw-cutting lathe with a swing of $36''$ and a bed of $20'$, having a horizontal feed along side; one small planer with a $5'$ table and $2'$ square under the cross head; another planer with a $10'$ table and $3'$ square under its cross-head; one boring mill; one radial drill, so constructed as to permit of use at any point of a circle five feet in radius; and several small drills and lathes.

These tools are all driven by a 60-horse-power engine used as 40-horse-power. This engine, as well as all the others, is fired with coke siftings at an expense of fifty cents *per diem* for fuel.

A single line of shafting extends nearly the entire length of the shop, and the majority of the machines are belted directly from this line shaft. Several small machines of peculiar motions or gearing have secondary shafts from which they are belted—the balance wheels being so adjusted that the insertion of the work into the various machines causes no perceptible variation in the motion of the machinery.

The furnace room, $120' \times 25'$, used for bending T or I iron, is provided with two furnaces, a levelling bed, several small presses for bending heavy beams, and one large hydraulic press.

The furnaces are reverbatory; the space for the reception of the bars in the large furnace being $30' \times 2'\ 6'' \times 1'\ 3''$, used for heating long iron beams, as those used in ship-building, preparatory to bending or straightening. The small furnace is $12' \times 4' \times 1'\ 3''$ for the same space, and is used for shorter beams.

The levelling bed, conveniently near the furnaces, consists of heavy blocks of stone pierced with holes, which receive uprights of different lengths according to the curvature required. The size of the bed may be varied by varying the number of the blocks. It is principally used for bending ship beams.

The presses are arranged to render available hydraulic pressure in straightening heavy beams. One large hydraulic press is used for the purpose of pressing out a peculiar shaped piece of $\frac{1}{8}''$ iron used in gas-works. The press not only gives it the required curves, but also cuts it of proper shape.

The flange room, $55' \times 26'$, is used for cutting off the flanges of T or I iron beams preparatory to joining them to flat surfaces, and has four forges. The blacksmiths' shop, $70' \times 55'$, has seven forges and one steam hammer.

There are now about 450 men employed at the works: from 1200 to 1500 are required when in full blast. The Montauk and Catskill are having iron beams placed in them and their decks raised. The torpedo target ordered for use at Willet's Point, lies on the wharf ready for floating.

The Company are preparing to lay rails upon various parts of the property, which being provided with suitable cars, it is expected will facilitate handling various articles while in process of manufacture. The water front of two hundred feet, and a mould loft, $180' \times 50'$, afford requisite means for carrying on the ship-building branch of the Company's work.

NEW YORK

AND

LONG ISLAND COIGNET STONE CO.

READ BEFORE THE ESSAYONS CLUB OF THE CORPS OF ENGINEERS,

MAY 30, 1874;

BY

LIEUT. PHILIP M. PRICE,
CORPS OF ENGINEERS.

NO. XXXIII. PRINTED PAPERS.

Printed on the Battalion Press.
Sergt. Carmichael & Pvt. Redfield, Printers.

NOTE.

This paper was prepared in compliance with instructions issued from the Headquarters of the Battalion of Engineers—under approval and direction of the Hon. Secretary of War and the Chief of Engineers—directing each officer of the Battalion to visit and examine, during the winter suspension of drills, some specified public work or manufacturing establishment. By request it was read before the Club; and being considered to contain information of interest to Engineer officers, it was ordered to be printed.

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THE NEW YORK AND LONG ISLAND COIGNET STONE CO.

A paper read before the "ESSAYONS CLUB" of the Corps of Engineers, on May 30th, 1874, by Lieutenant Philip M. Price, Corps of Engineers.

THE MANUFACTORY.

The manufactory of the New York and Long Island Coignet Stone Company is in Brooklyn, on Third Avenue between Third and Sixth streets. The ground occupied by the Company has an area of five acres, and is intersected by the Fourth street Basin, which, connecting with Gowanus Canal, gives the Company facilities for receiving their materials, and shipping their stores direct by water.

The factory is a substantial frame building, thirty-two feet in height, covering an acre of ground, and in addition to containing the offices and machinery, serves as a storehouse for the sand and cement, and a very large number of moulds or patterns. There is but little machinery in it, the mixing of the ingredients being the only part of the process of manufacture not performed by hand labor. A large engine, mounted on wheels, supplies the power, which turns a long horizontal shaft supported at a height of about twenty feet above the floor. The motion of this shaft is transmitted by belts to the machinery of the malaxators, also mounted on wheels, and placed side by side under the shaft; only as many of them as are needed being operated at one time. In the Superintendent's office, where samples of the stone produced are frequently tested, are a powerful hydrostatic testing press, by which a crushing power of 120,000 pounds can be applied, and a machine for testing the tensile strength.

The works are capable of turning out fronts for ten ordinary houses per day, besides a large quantity of ornamental stone; and when working to their full capacity employ about one hundred men.

ORIGIN OF THE PROCESS.

The process of making artificial stone employed by this Company was discovered and patented in 1856 by M. Francois Coignet, of Paris, who gave it the name of Béton-Aggloméré, though it is now generally called Béton-Coignet, or Coignet stone. It was

at first received with much distrust; but the Government engineers, after experimenting upon it for the period of two years, having pronounced it equal in appearance, strength and durability to the natural stone, and unaffected by heat, dampness, or frost, the French Government adopted it in many of its public works.

Patents covering the entire process and the machinery employed, were granted to M. Coignet in the United States in 1869, and under these the N. Y. and L. I. Coignet Stone Co. is working.

THE MATERIALS.

The materials used in the manufacture are cement, hydraulic lime, sand and water. Only the heavy Portland cement is employed, and this is manufactured especially for the Company, and imported by them. Great care is taken to secure a uniform quality of cement, and every lot is carefully analysed before use, as any variation in the composition of the cement renders necessary a corresponding variation in the proportions of the other ingredients, and affects the nature of the stone produced. If the cement contains more than the proper proportion of clay, the stone made from it will crack on exposure to the air and consequent drying, but will not be open to this objection if placed under water. This defect is remedied by adding a small percentage of hydraulic lime to the matrix, and as far as I could learn, this seems to be the only case in which lime is now used, although in the original patents it is specified as the principal ingredient of the matrix, the proportion of cement being comparatively small.

The sand is obtained from Northport on Long Island, and is of the same kind as that used for smoothing brown stone. It is a clean, sharp, silicious sand, and does not require washing. It is dried before use. It is essential that the sand should be of the first quality, since upon it mainly depends the durability of the stone, especially when used for flagging or steps.

The sand in Coignet stone bears the same relation to the cement paste (cement and water) that the broken stone in concrete does to the mortar (lime or cement, sand, and water), and the proportion of it used is determined on the same principle, viz.: That the volume of matrix should always be somewhat in excess of the volume of voids in the materials to be united, the excess being added as a precaution against imperfect manipulation. The proper proportion is determined practically by weighing a box of a cubic foot capacity, filled with the dry sand—water is then poured in the sand until all the voids are filled, and the box re-weighed. The increase is the weight of the water, from which, and the relative weight of water and cement paste, the proper proportions of the latter can be determined. The actual proportions used are from 3 to 6 parts of sand to 1 of cement, depending upon the kind and quality of stone desired.

A most important feature in the preparation of the stone-paste is the use of the proper quantity of water, since upon the consistency of the paste depends the process of agglomeration, as it is called, which is one of the principal points of the patent. Coignet's malaxator has a device for supplying the proper amount of water; but this is not used at the Brooklyn works, the water being poured from a tin cup upon the other materials in the machine by the man in charge, the amount, which is from thirty to thirty-five parts to one hundred of the cement, being regulated by the appearance of the matrix, of which his experience must enable him to judge.

The degree of moisture must be precisely such that the effect of each blow of the rammer shall be distinct, local and permanent, without disturbing the surrounding material compacted by previous blows. If it be too moist the mass will shake like wet clay, and if it be too dry, it will break up around the rammer like sand.

THE MALAXATOR.

It is impossible to produce a cementing material of suitable quality for Coignet stone by the ordinary method used for making mortars, it being necessary that the sand and cement should be thoroughly and uniformly mixed together, making a plastic or viscous paste with the minimum quantity of water, and that each grain of sand should be entirely coated with a thin stratum of this paste. These requisites are accomplished by a machine invented by M. Coignet and called by him a malaxator, a detailed description of which with drawings, is given in the Professional Papers of the Corps of Engineers, No. 19, by Gen. Q. A. Gillmore.

The machine mixes the materials thoroughly by a combined pressing and rolling motion, produced by two twin screws, having their helices interlocked and turning, and exerting their force in the same direction. The screws are held in a frame-work, mounted on wheels for facility of transportation, and inclined at an angle of about 25 degrees. The materials are thrown into a feeder at the lower end and come out at the upper, under which a wheel-barrow or box may be placed to receive them. The inclination also causes a more perfect mixture of the ingredients by retarding the progress of the matter, owing to its specific gravity.

The cement and sand, in the proper proportions, are passed through the machine two or three times, water being added by the man in charge until the mixture presents the appearance of a short paste or pasty powder. This prolonged trituration retards the setting of the cement, and increases the hardness of the stone.

By the introduction into the paste of coloring matters, such as ochres, oxides, etc., or fragments of natural stones, any variations in shade or texture may be produced, from buff or drab to the darkest gray or brown.

AGGLOMERATION.

The next step in the manufacture is the agglomeration of the stone paste, the object being to bring the grains of sand into as close proximity to each other as possible, and to expel all air from the paste. This is accomplished by ramming the paste, in thin layers, with iron-shod rammers, in wooden moulds or patterns, whose interior shape and dimensions correspond exactly to those desired for the stone. These patterns have a bottom and sides made of separate pieces, which, being joined together by screw-bolts, are readily detached from each other and the stone when the agglomeration is completed.

The mould being placed at a convenient distance from the malaxator, a quantity of the paste sufficient to cover the bottom to a thickness of about an inch is poured into it, spread with a rake, and packed by repeated blows of the rammer until its thickness is reduced about one half. The upper part of this stratum is thus left a smooth surface, which hardens promptly by the setting of the cement and the evaporation of the water, so that a perfect weld would not be formed with a second stratum placed on it. To obviate this difficulty the surface is scratched with a fragment of saw blade before pouring in the materials for the next stratum, which, and the succeeding strata, are treated in the same manner as the first, until the mould is full, when the upper surface is smoothed off, the mould turned over on a layer of sand, the bolts removed, and the parts of the mould detached from the stone.

The stone hardens to a considerable extent during the agglomeration. So much, in fact, that the Superintendent informed me, that for the purpose of testing it, some of the stone was laid in their new office building on the day it was manufactured, and has stood well. Under ordinary circumstances, however, the minimum time allowed for hardening before using the stone is three weeks.

STRENGTH AND DURABILITY.

In regard to the strength, durability, and applications of Coignet stone, the fullest reports published in this country are those of Gen. Gillmore and Mr. Leonard Beckwith, C. E., U. S. Commissioner to the Paris Exposition of 1867; and, although I was shown many reports and certificates from other eminent civil engineers and architects all testifying to the great merits of the stone for various purposes, I will give a few extracts from the reports of the two former only.

As to strength and durability, General Gillmore says:—

"Béton Coignet becomes in process of time as impervious to water as many of the compact natural stones, while its natural strength exceeds that of the best qualities of sandstone, some of the granites, and many of the limestones and marbles."

"It is injured by freezing before it has had time to set. Important works should not, therefore, be executed during the winter in cold climates."

"The effect of freezing on newly made béton is to detach a thin scale from the exposed surface, producing a rough and unsightly appearance: but the injury does not extend into the mass of the material, unless the frost be very intense."

"Pieces of statuary and other specimens, ornamented with delicate tracery, have been exposed for five consecutive winters to the weather, in New York City, without undergoing the slightest perceptible change."

"Chemical tests have shown this béton to be practically impervious to water. Two small specimens, each weighing about two and a half grammes, were tried by Dr. Isidor Walz, chemist, of New York City. Their specific gravity was 2.305. They were immersed in water fifteen minutes, and then kept four days in air, saturated with moisture. One of the specimens did not increase in weight at all during the interval, while the other absorbed $\frac{16}{100}$ of one per cent. of moisture."

"In constructing the municipal barracks of Notre Dame, Paris, the arched ceilings of the cellars were made of this béton, each arch being a solid mass, * * * the rise in all cases being one-tenth the span, and the thickness at the crown 8.66 inches. * * * One of these vault arches, having a span of seventeen and a half feet, was subjected to three severe trial tests, viz.:—

First, a pyramid of stone-work weighing 36 tons, of 2,000 lbs. each, was placed on the centre of the vault.

Second, a mass of sand, 13 feet thick, was spread over the surface of the same vault.

Third, carts loaded with heavy materials were driven over it. In no instance was the slightest effect produced."

Mr. Beckwith gives the following table showing the relative bearing and tensile strength of the different building materials named.

	Mortar.	Concrete.	Brick.	Limestone.	Sandstone.	Coig. Agg.	Granite.
Crushing strength in lbs. per sq. in.	280 to 2100		550 to 1700	4000 to 5500	2200 to 5500	2634 to 7495	5500 to 11000
Tensile strength in lbs. per sq. in.	50 to 290	77 to 360	115 to 300	120 to 864	180 to 900	288 to 426	

"A cubic foot of béton-coignet weighs about one hundred and forty-five pounds."

The bearing strength of the Coignet stone given in the above table, is the result of experiments made in France in 1864, and is considerably less than the average strength of that now made by the N. Y. and L. I. Co., while many specimens of their work have resisted a crushing strain of 12,000 lbs. to the square inch.

To determine the resistance of Coignet stone to high degrees of heat, a writer in the April number of Van Nostrand's Magazine of 1873, "subjected samples of the various natural and artificial stones to the following tests. Pieces of the different kinds were heated to redness, and then allowed to gradually cool. Other pieces of each kind were heated to redness and immediately plunged into cold water. Quincy granite was in both cases disintegrated. White marble was much weakened in the first test, so as to be easily broken by the fingers; in the second it was rendered quite friable. Soapstone was in either case affected but very slightly, if at all. Brownstone (good specimens from Portland, Ct.,) in both cases was disintegrated quite as much as the granite. Brownstone from Seneca, Md., (the most compact brownstone ever examined by the writer) in both tests appeared to be uninjured. Nova Scotia freestone was somewhat weakened, but endured both tests better than the other natural stones, except soapstone and Seneca brownstone. Of the artificial stones, * * * the Coignet stone endured both tests equally well with the soapstone and the Seneca brownstone, not appearing to lose any of its strength.

APPLICATIONS.

Of the applications of Coignet stone in Europe, Gen. Gillmore says "the most important and costly work that has yet been undertaken in this material, is a section, thirty-seven miles in length, of the Vanne Aqueduct for supplying water to the city of Paris.

"This aqueduct, which traverses the forest of Fontainebleau through its entire length, comprises two and a half to three miles of arches, some of them as much as fifty feet in height; and eleven miles of tunnels, nearly all constructed of the material excavated—the impalpable sand of marine formation known under the generic name of Fontainebleau sand. It includes, also, eight or ten bridges of large span (seventy-five to one hundred and twenty-five feet) for the bridging of rivers, canals, and highways.

"The smaller arches are half circles, and are generally of a uniform span of $39\frac{37}{100}$ feet, with a thickness at the crown of $15\frac{3}{4}$ inches. Their construction was carried on without interruption through the winter of 1868–9 and the following summer, and the character of the work was not affected by either extreme of temperature. The spandrels are carried up in open work to the level of the crown, and upon the arcade thus prepared, the aqueduct pipe is moulded in the same material, the whole becoming firmly knit together into a perfect monolith. The pipe is circular, six and a half feet in interior diameter, with a thickness of nine inches at the top, and twelve inches at the sides at the water surface. The construction of the arches is carried on about two weeks in advance of work on the pipe, and the centres are struck about a week later.

"Water was let into a portion of this pipe in the Spring of 1869, and M. Belgrand,

inspector-general of bridges and highways, and director of drainage and sewers of the city of Paris, certified that *the impermeability appeared complete.*"

"Another interesting application of this material has been made in the construction, completed, or very nearly so, of the lighthouse at Port Said, Egypt. It will be 180 feet high, without joints, and resting upon a monolithic block of béton, containing nearly 400 cubic yards."

"An entire gothic church, with its foundations, walls and steeple in a single piece, has been built of this material at Vésinet near Paris. The steeple is 130 feet high, and shows no cracks or other evidences of weakness."

"Over thirty-one miles of the Paris sewers had been laid in this material prior to June, 1869, at a saving of 20 per cent. on their lowest estimated cost in any other kind of masonry."

"Several large city houses, some for places of residence, and others for business purposes, have been constructed, and many others are in contemplation. In these the entire masonry, comprising both the exterior and the partition walls, the chimneys with flues, cellar arches, cistern, etc., is a single monolith of béton aggloméré."

"An interesting application of this material in the construction of a hollow sustaining wall was made at the cemetery of Passy, in supporting a bank of earth 29½ feet in height. In that wall the volume of the hollows is equal to 53 per cent. of the aggregate volume of béton. The hollows were filled with dry earth."

"The jetties at the entrance of the Suez canal are built of béton-coignet. The construction is not monolithic, the béton having been formed into blocks, weighing about 20 tons each, on land, where they were allowed to harden for two or three months before they were used."

"Many other interesting applications of this material were examined, of which it is not deemed necessary to make any special mention, except that in combined stability, strength, beauty and cheapness, they far surpass the best results that could have been achieved by the use of any other materials, whether stone, brick, or wood."

Notwithstanding its recent introduction into this country, the Coignet stone has already been extensively used for building and ornamental purposes; as many as fifty dwellings, mostly of imitation brown or sandstone, having been built of it in Brooklyn alone.

It was also used for the arches, columns, and traceries of the great Roman Catholic Cathedral corner of 5th Avenue and 50th street, New York City; and it has furnished the entire masonry for several smaller churches, the cheapness and beauty of ornamental work of this material rendering it peculiarly adapted to this class of building.

The largest monolithic constructions of this material are the Cliftridge span in Prospect Park, and the receiving tomb at Evergreen Cemetery; the interior area of the latter being 55 by 31 feet, and the height of the crown of the arch 18 feet, the thickness of the walls being two feet. The centre of the arch was struck seven days after its completion. In these constructions, as well as in its many other applications in this country, the Coignet stone has fully maintained the reputation it had already acquired in Europe.

COST.

Coignet stone is in general from 25 per cent. to 50 per cent. cheaper than the natural stone. A house front worth two thousand dollars in natural stone, is worth about one thousand in Coignet stone; while an ornamental vase costing two hundred and fifty dollars in natural stone, could be obtained for thirty dollars in Coignet stone.

It is more expensive than brick construction foot for foot; but the greater strength of this material, and the absence of the weak mortar joints, and poor bond made by bricks but eight inches long, sometimes make it cheaper than brick, especially in arches and other constructions requiring great strength.

An ordinary block, smooth on all sides, can be made of Coignet stone for about the price of the natural stone of same contents in the rough, so that the cost of cut stone work exceeds that of béton-coignet work by the cost of dressing the natural stone. The plainest work, in large masses, is worth about one dollar per cubic foot.

BRICK-YARD

AND

NEW BRICK MACHINE.

READ BEFORE THE ESSAYONS CLUB OF THE CORPS OF ENGINEERS,

MAY 30, 1874;

BY

LIEUT. THOMAS N. BAILEY,
CORPS OF ENGINEERS.

NO. XXXIV. PRINTED PAPERS.

Printed on the Battalion Press.
Sergt. Carmichael & Pvt. Redfield, Printers.

NOTE.

This paper was prepared in compliance with instructions issued from the Headquarters of the Battalion of Engineers—under approval and direction of the Hon. Secretary of War and the Chief of Engineers—directing each officer of the Battalion to visit and examine, during the winter suspension of drills, some specified public work or manufacturing establishment. By request it was read before the Club; and being considered to contain information of interest to Engineer officers, it was ordered to be printed.

This note is prefixed by a vote of the Club, in order to explain the peculiar character, and necessarily limited scope of the paper.

BRICK-YARD AND NEW BRICK MACHINE.

A paper read before the "ESSAYONS CLUB" of the Corps of Engineers, on May 30th, 1874, by Lieutenant Thomas N. Bailey, Corps of Engineers.

The brick-yard of Mr. A. T. Provost is situated on the shore of Long Island, about three miles east of Northport.

A substantial brick building contains a 70-horse-power engine, work-shop, store-rooms and office. The pits, moulding machines and kilns are protected by large wooden sheds. The general arrangement appears systematic and made with due regard to convenience and economy.

About 400 yards west along the shore a tramway leads to the clay bed, an extensive deposit, which I am informed continues more than a mile in from the shore, and as far as examined by me, the outcropping along the bank was from two to three hundred yards.

Where the clay is being excavated it is found covered with from one to three feet of ordinary earth or "stripping," its surface being conveniently situated twelve feet above high water: in depth it is worked to the latter level, how much farther it extends is not known.

The material is of a dull brown color, no reddish or yellow hue distinguishable: of a very uniform appearance and free from sand or pebbles, with the exception of an occasional "clay-dog." It is always more or less moist. The stripping is first removed: the excavation then proceeds in the form of steps, the workman using a shovel only, and with ease cutting out rough cubes about eight inches on a side. These are thrown directly into a car, the tramway being shifted near the wall as the excavation advances.

The pits, or pug-mills, for mixing the engredients, four in number, consist each of a circular basin 30 feet in diameter and three feet deep. By shafting and cog-wheel gearing, a light iron wheel, six feet in diameter, is caused to move spirally on the bottom of the pit, utilizing nearly its entire area. The sand employed is taken from the sea-shore near the pits. It is clean and sharp, and generally so free from pebbles, as to render screening unnecessary.

The clay is deposited in the basin together with sand, in the proportions of two volumes of clay to one of sand—from three to four pecks of coal-dust are added for each thousand of bricks to be produced. This is to assist in burning. Water is then let on from a pipe above the pit, in sufficient quantity to admit of ease in working. The mixing then proceeds by the revolution of the light iron wheel before mentioned.

Each pit will contain enough material for 36 thousand bricks, and requires from three to five hours for tempering.

When the mass appears properly mixed and is of about the consistency of working putty, it is removed in barrows to the moulding machines, two of which are employed in connection with each pit.

The Wiles' Moulding Machine used, is a vertical pug-mill seven feet high and four feet in diameter at top, smaller at the bottom. Within revolves a vertical axis carrying knives, which continue the tempering process and force the material against a sliding door at the bottom of the mill. The moulds are wooden trays, divided by partitions into six compartments $8\frac{1}{2} \times 4 \times 2\frac{3}{4}$ inches. The moulds are placed by hand under the aperture closed by the sliding door: upon opening the latter, the material enters the moulds, in which it is somewhat pressed by plungers.

The trays are then withdrawn, the upper surfaces of the blocks struck off smoothly, and the moulds with contents removed to the drying-ground, where the bricks are carefully piled with interstices admitting free circulation of air. They are protected by covering when rain or dew are expected. The time required for drying is much influenced by the weather, the average being three days.

In this process, a block $8\frac{1}{2}$ inches in length when moulded, will shrink $\frac{1}{4}$ inch—its length will be reduced to a little less than 8 inches by burning.

When the bricks are sufficiently dried to prevent warping by burning, they are transferred to the kiln-shed—a wooden building 200×75 feet, open at the ends, the roof being of boards arranged so as to be removed when the heat becomes dangerously intense. From six to one hundred thousand bricks are burned at once.

The pile built is rectangular in form, the sides receiving a slight batter. At the base of the kiln, arched openings or furnaces, eighteen inches wide by two and a half feet high, are built of the dried blocks, these openings projecting through the width of the kiln. The bricks are then carefully piled in regular order, with openings between them for equal dissemination of heat.

The pile is carried to a height of fifteen or eighteen feet, the last two layers being of "pale" or "soft brick" from a previous burning, which by re-burning becomes hard brick.

The walls of the kiln, eight inches thick, are of dried blocks, containing five times as much coal-dust as the ordinary brick. This is to counteract the chilling effect upon the exterior. To confine the heat, the sides of the kiln are next well coated with clay, or "mudded," the openings of the furnaces are reduced by iron door-frames and doors, by which the draught is regulated.

Well dried wood only is used as fuel. The fires are kept down at first, being gradually increased day after day, until the workman "sees" the heat coming out at the top: the intensity is then uniformly diminished until the fires gradually die out. The average time occupied in burning is six and a half days and nights, the consumption of wood being one-sixth cord per thousand bricks. The greater the number of bricks in a kiln the less fuel is used per thousand.

The blocks forming the furnaces, called "arch brick," are vitrified and more or less warped by the heat, while those near the top of the kiln are under-burnt, of a lighter color, and known as "pale" or "soft brick."

The body of the kilns inspected presented a very uniform light red appearance. The bricks from this part are the best; they are commercially classed as "hard brick"—this includes "arch brick."

Most of the pale bricks are sold: some of them are re-burned to hard brick—they are about six per cent. of the amount in the kiln.

Only two pits are now in use, one foreman, one engineer and ten hands being employed. One pit is emptied in the morning, two men being occupied in feeding material at each moulder. At the moulder, one stripper is on duty, assisted by two or three men at the moulds. Thirty-six thousand bricks are moulded by 10 or 11 A. M., when the men are transferred to the clay bed or kiln-shed.

With twenty men operating all the machinery, the daily production would be seventy-two thousand.

HUBBARD & FARR'S BRICK-MACHINE.

At this yard is the first brick-machine constructed under Hubbard & Farr's patent: it was erected in the Fall of '73.

In general appearance it is a large, open, iron cylinder, ten feet in diameter and ten feet long, rotating upon its horizontal axis. A pug-mill, with horizontal axis, abuts against the middle of the cylinder.

The machine is constructed mainly of cast iron, and weighs seventy tons. In a hopper above the pug-mill the ingredients are placed, and the pressed bricks delivered at the opposite side of the cylinder upon an endless band.

The construction of the machine will be understood by reference to the sketch,

Plate I., Fig. 2, giving a general idea of a portion of the exterior surface of the cylinder, its axis being in the direction XX. AB is part of a cast iron ring, with cavities or pockets (c. d. e. f) at intervals, extending half its thickness. Corresponding with each of these pockets is a mould (g. h. i. k.), shown in side view at Plate I., Fig. 3, its cross-section being equal to the bed of the brick.

The mould extends completely through the ring. A plunger (P. P′) is carefully fitted at each extremity of the mould, the plunger-rod running in guides and having a wrist joint at its extremity to insure proper action. The end of the plunger-rod is furnished with two friction rollers constrained to move along the guides m. n.

Now suppose all parts, except the guides, to move in the direction of the arrow:— The clay being first forced into the pockets and moulds by the pug-mill, the plunger (P) advances and punches out material for a brick, by a continuation of its motion the material is further compressed and its surfaces rendered smooth by motion along the polished sides of the mould. The plunger (P′) now retires, while (P) moving on forces the block out of the mould upon an endless band, by which it is conveyed a convenient distance and then removed by hand, without danger of injury, to be dried. The plungers then reverse their motion and the operation is repeated.

The pug-mill is of iron, seven feet long, and 3½ feet in diameter at base, less at its mouth.

The ingredients, partly mixed in proper proportions, become thoroughly tempered, and gradually forced by the revolution of twenty-eight inclined blades, towards its mouth, where two propeller-shaped blades press the mixture well into the pockets. It is here that the material receives its greatest pressure. The inventor contemplates placing another pug-mill opposite the first, thus doubling the efficiency of the machine. To facilitate the transfer of the block to the band, the face of the ejecting plunger is very highly polished, and when it reaches its lowest position it is carefully wiped and oiled by a workman. This is a troublesome operation and a cause of delay—a mechanical contrivance is proposed by the inventor to perform this duty.

The machine is furnished with thirty pockets, and is expected to make two revolutions, producing sixty bricks, per minute. At the time I saw it, the production was twenty-three blocks per minute; due, probably, to the fact that it is a roughly built experimental model, much power being wasted through inferior workmanship in its construction. It appears much too heavy. Future ones will be smaller, containing from eighteen to twenty pockets. The cost is estimated at $6,000.

The workmen required, are— two men with barrows carrying material to the hopper; one at the pug-mill; one oiler, and two boys to receive and carry off the blocks; making a total of six hands, exclusive of engine.

A smooth face is required upon the ejecting plunger so that the block formed may be readily detached by the band; but the face of the opposite plunger may receive any design to be stamped upon the brick. One in the machine inspected, was arranged to produce a block with paneled face; another gave a tapering or arch brick. By a simple screw adjustment of the plungers, the thickness of the block can be readily varied

None of the bricks from the machine have yet been burned; but although they do not promise to equal in appearance a Philadelphia pressed brick, yet they are far superior to the ordinary article. The advantages being, perfect uniformity in production, smooth surfaces, and true, well defined edges. They contain six per cent. more material than unpressed bricks of same size.

It is not proposed to manufacture a highly finished brick, but an ordinary wall brick much better than those now in market, and at a price very little, if any, in excess.

CANAL.

A canal and breakwater have been constructed at this yard for convenience and protection of loading vessels.

From the map herewith, it will be seen that the general direction of the shore-line is east and west. The prevailing winds are from the north-east, frequently giving rise to very heavy seas. Storms also come from the north-west, but are less frequent and not so violent.

The soil is principally sand, mixed with some clay and occasional boulders. The site of the canal was the outlet of an extensive pond. About opposite this outlet and 300 feet from shore, a sand-bar has formed; visible at low water, its general direction being parallel to the shore-line. The rise of tide is seven feet. The canal is of rectangular cross-section, width 32 feet in clear, projecting perpendicularly about 300 feet inshore. The depth of water at low tide is five feet. The walls are formed of a single row of 8-inch piles, two and a half feet apart, strengthened by land ties. Two and a half inch sheeting is spiked horizontally to the piles. This sheeting, for some peculiar reason, is placed in front of the piles, or towards the centre-line of the canal. At the head of the canal an ordinary water-gate is placed: above this is a corduroy apron permitting a fall of water without scour. It was the original intention to place a lock at the mouth of the canal, but this was abandoned in favor of the breakwater.

The breakwater is built in two arms, the channel between forming a continuation of the canal. Its general direction is perpendicular to prevailing winds; length 300 feet; opening between heads is 100 feet.

Each arm consists of two parallel rows of piles, fifteen feet apart, supporting an open crib-work within, and stiffened by occasional connecting ties. Inside, broken stone

is placed. The piles are driven six feet in the sand. The heads of the breakwater are strengthened by heavier mooring piles. The arms project about twenty feet in-shore: sheeting is used on the land portion, and is placed behind the piles. The canal has been in operation about one year; during this period the sand-bar has suffered no material change. Heavy north-east storms, however, are gradually forming shoal water between the bar and shore east of longer arm. Gales from the north-west, it will be seen, blow almost directly in the opening of the breakwater; and when they occur, a deposit of sand is made between the heads, which, I am informed, is cleared away by the next north-east gale. Some trouble has, however, been experienced from sand thus deposited. Its removal is facilitated by the action of running water through the channel. Littoral currents have not been observed.

The cost of the work was about $15,000, and thus far it appears to afford a safe harbor, on a lee shore.

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Fig. 1.

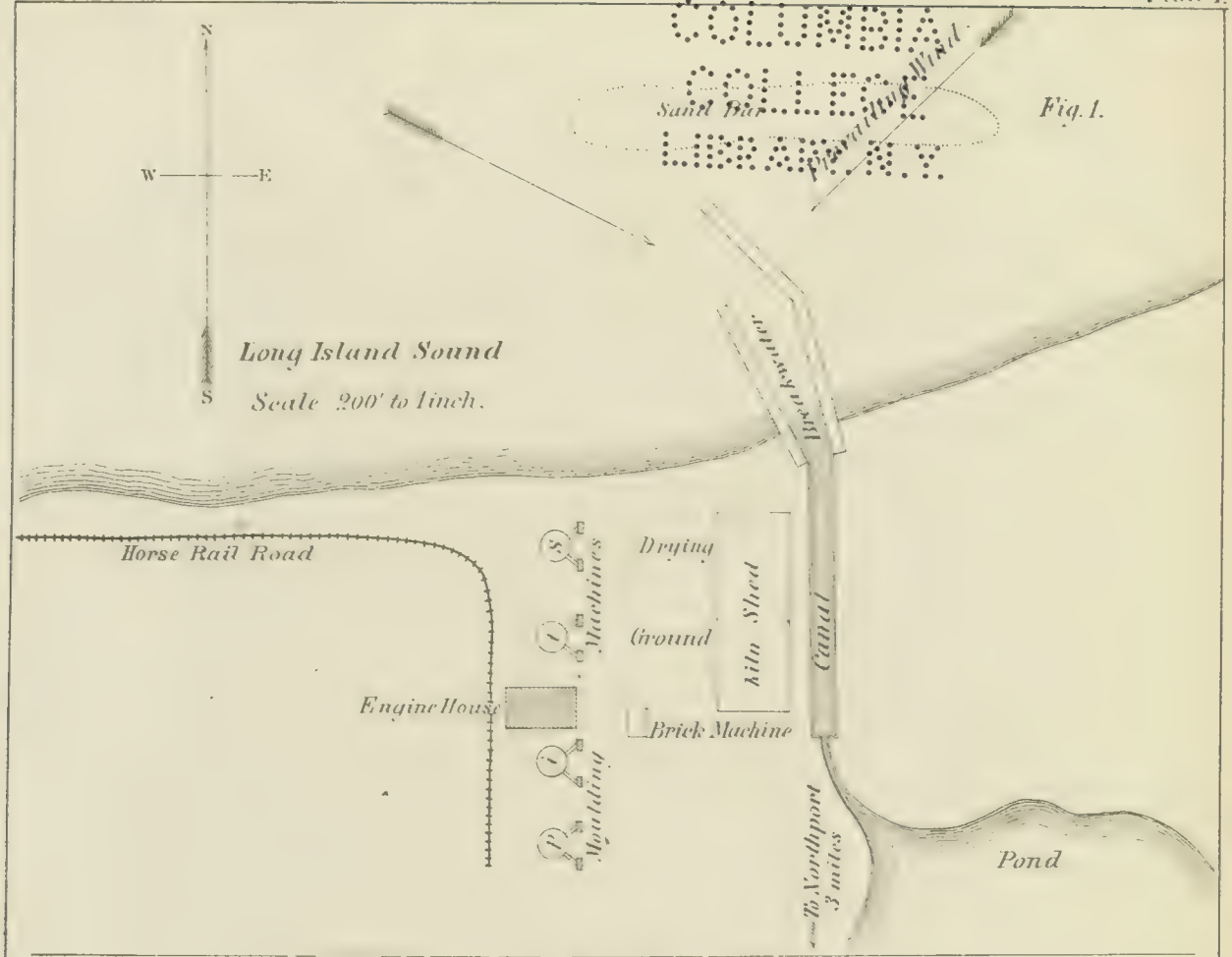


Fig. 2.

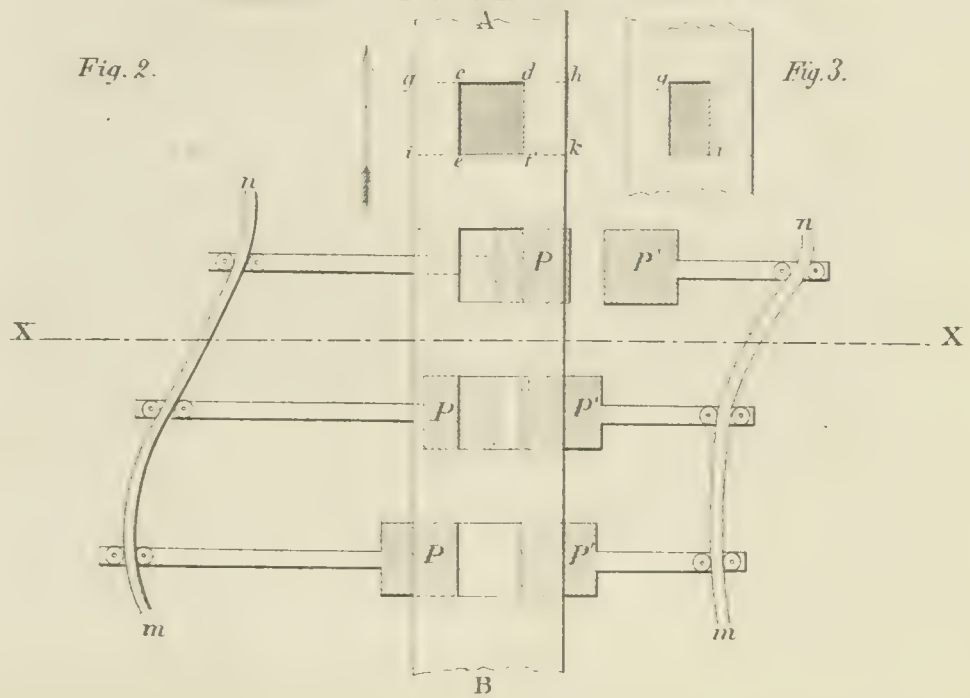


Fig. 3.

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NOTES

ON

THE HOOSAC TUNNEL.

READ BEFORE THE ESSAYONS CLUB OF THE CORPS OF ENGINEERS,

JUNE 3, 1874;

BY

CAPT. JAMES C. POST,
CORPS OF ENGINEERS.

NO. XXXV. PRINTED PAPERS.

Printed on the Battalion Press.
Sergt. Carmichael & Pvt. Redfield, Printers.

NOTE.

This paper was prepared in compliance with instructions issued from the Headquarters of the Battalion of Engineers—under approval and direction of the Hon. Secretary of War and the Chief of Engineers—directing each officer of the Battalion to visit and examine, during the winter suspension of drills, some specified public work or manufacturing establishment. By request it was read before the Club; and being considered to contain information of interest to Engineer officers, it was ordered to be printed.

This note is prefixed by a vote of the Club, in order to explain the peculiar character, and necessarily limited scope of the paper.

THE HOOSAC TUNNEL.

A paper read before the "ESSAYONS CLUB" of the Corps of Engineers, on June 3rd, 1874, by Captain James C. Post, Corps of Engineers.

It is not the purpose of this paper to give a complete history of the tunnel from its inception down to the present time, carrying it through the years of controversy and legislation that it passed, but merely to give some of the interesting engineering facts connected with, and some of the methods employed in the prosecution of this great undertaking.

The project of a tunnel through the Hoosac mountain was first proposed in 1825, in the report of a legislative commission appointed to ascertain the practicability of a canal from Boston to the Hudson river. This commission reported in favor of the route by way of the Deerfield and Hoosac rivers, including a tunnel through the Hoosac mountain. The project, however, was soon afterwards abandoned in favor of a railroad along the same route; this route being the only one by which Boston and the Hudson river could be connected by a railroad with easy grades.

The Hoosac mountain—through which this tunnel passes—a profile section of which is given on Plate II., has two crests or summits, with a valley between them. The Hoosac river washes its western base, and the Deerfield river its eastern. The eastern summit is 1,499 feet above the Deerfield river, and the western 1,788 feet above the Hoosac river. Both of these rivers, at the points selected for the entrances to the tunnel are at the same height above tide water, which rendered it necessary to enter the mountain on both sides at the same elevation. Proper drainage is secured by a summit in the middle, from which the grade descends to either portal. The direction of the tunnel is nearly east and west, and its length, as commenced in 1856, $4\frac{84}{100}$ miles.

In 1855, the first contract for excavating the tunnel, was made with E. W. Sewell & Co., of Philadelphia, but this, as well as a second one made with the same parties in the following year, was annulled before the work was fairly begun. In July, 1856, a contract having been made with Herman Haupt & Co., the work was commenced on both

sides of the mountain. They succeeded in piercing the mountain from the east side westward a distance of 2,400 feet and from the west side eastward about 315 feet. The rock on the east side was found to be mica slate with occasional seams of quartz, and that on the west side limestone. The limestone as they advanced soon disappeared, and a disintegrated mica schist was encountered. This, with the water that was very abundant in this part of the tunnel, formed a quicksand, and rendered further progress extremely difficult. Hoping to escape this a little farther on, they went about half a mile farther up the mountain, and opened there what is called the west shaft—318 feet deep to the grade of the tunnel. From the foot of this shaft they started headings towards both the east and west, making in both of these headings an advance of only 56 feet. In 1862, financial embarrassments caused the abandonment of this contract, and from this to 1866 the work was carried on by the state of Massachusetts, represented by a board of commissioners, the State Engineer having immediate charge.

In 1863, the commissioners concluded to abandon the old working at the west end, and make it into an open cut for nearly 600 feet—thus reducing the length of the tunnel to $4\frac{74}{100}$ miles. The central shaft was located and work was begun upon it during this same year. This shaft was in the form of an ellipse, its dimensions being 27 feet along the line of the tunnel and 15 feet across it. It was expected that this shaft would assist materially in ventilating the tunnel, as well as be of great use in expediting the actual work upon it by enabling four headings to be worked instead of two. It undoubtedly shortened the time of construction by at least a year, but it is yet doubtful whether it will be of much value as a ventilator.

In the year 1866, the west end was put under contract to Mr. B. N. Farran. The following extract from the Commissioners' Report for the year 1866, gives an account of the operations as conducted by him: "At the beginning, the invert and the sides to the spring of the arch were laid with five courses of brick and the arch was six. The masonry afterwards was strengthened to meet the effect of the soft ground and increased pressure, to eight bricks thick all around. The excavation of the drift is carried on with two galleries. The lower one is of timber and is at the bottom 3 feet below the grade of the road. This gallery is 10 feet by 10 feet. The upper gallery is also of timber and is 10 feet wide by 4 feet high, and the space between the galleries is about 10 feet. As the arch is driven in, the top of invert is $4\frac{1}{2}$ feet below the grade of the road, and 18 in. below the timbers of the lower gallery. The top timbers of the upper gallery constitute the top timbers of the tunnel during the excavation. They are supported above the masonry, and the arch is turned under them. Side drains 6 feet high by 4 feet wide are excavated ahead of the galleries to assist the drainage of the ground through which the

galleries and tunnels are driven. The water from this drain is let into the tunnel through its sides and runs out with the general drainage upon the invert below the road bed. Holes are left in the invert at proper intervals to facilitate the drainage. The side drains were afterward filled with stone and constituted a blind drain and also afford a proper support for the masonry.

In November of the same year while working from the west shaft eastward, they came upon a seam running across the stratification of the mountain, from which the water came out in such large quantities that it was estimated that the flow was about 160 gallons a minute. This gained so rapidly upon them, notwithstanding their attempt to check it by driving wooden plugs into the seams, that work had to be stopped. They then temporarily abandoned this shaft and began to open a new shaft westerly 264 feet having the dimensions of 6 feet by 13 feet.

In the following year the plan of running an adit from the west end to the west shaft to take the water from the west shaft and heading, and discharge it from the west end of the tunnel, was adopted, as soon as this was accomplished, work was again commenced in the headings from the west shaft, and continued until it was determined to try again the plan of letting the entire work by contract, when all work was suspended. This was in September 1868.

After Mr. Farran had completed his first contract, a second was given him in 1867, to continue the work on the brick archway. Under these two contracts he completed in all 931 feet of brick-work.

The present contractors, Messrs. F. Shanly & Co., commenced work upon the tunnel January 1st, 1869. At this time the tunnel at the west end was open from the portal for 4056 feet, or a little more than three-fourths of a mile—the 931 feet of brick archway constructed by Mr. Farran, being the only part completed. At the east end the tunnel was open for 5282 feet, or about a mile, and full size for only half the distance. The central shaft had been opened to a depth of 583 feet, there remaining still 447 feet to be excavated. The contract required that the tunnel should be 24 feet wide and 22 feet high through solid rock (Fig. 3, Plate I.), and through soft material, where a brick lining would be required, the brick arch and sides were to be 2 feet 4 inches thick, the arch to be 26 feet wide and 26 feet high (Fig. 2, Plate I.) The State Engineer in charge was to give the lines and grades and be responsible.

The grade fixed was 26.40 feet per mile from the summit under the central shaft toward either portal.

Under this contract work was commenced by April 1st, at the east end heading and central shaft, and about July 1st at the west end heading. No particular difficulty was-

encountered at the east end, though they were somewhat delayed by the change in the inclination or dip of the strata. This at first was about 80°, but as they advanced it became nearly horizontal, which rendered the rock much more difficult to displace by blasting. Their rate of progress, however, averaged about 140 feet a month.

In August, 1870, the central shaft was completed; and in the following month headings were started from the bottom towards the east and west. These were continued until the following year, when the work in the western heading was interrupted and stopped by a large influx of water. This they endeavored to stop by plugging, and afterwards by building a dam across the heading, hoping by this means to hold the water in check till the east heading from the central shaft and the heading from the east end came together, which would allow the water to flow out of the eastern portal, and save the necessity of raising the water through the central shaft. Both of these plans had to be abandoned, however, as the pressure was too great. After this, work in both of the headings was stopped until pumps could be put up that would lift the water the 1009 feet up the central shaft to the outlet. As soon as the shaft and headings were cleared of water work was again commenced. They advanced however, but a short distance in the western heading before the increase of water became so great, that it was feared that farther progress might develope it in such large quantities that it would be beyond the capacity of the pumps provided for its removal. They therefore stopped work upon this heading, trusting to the pumps to control the water already developed, till the junction could be made. This was accomplished in December, 1872. From this time the work of pumping was reduced to raising the body of water over a bench 12 feet in height, after which it followed the floor of the tunnel eastward. Work was then commenced on the west heading, when instead of following the grade of the tunnel during the excavation, they raised the floor of it so as to cause all the water to flow towards the east, and be discharged from the east end. In the meantime the work was progressing in the heading from the west end without interruption, though the advance was less rapid than in the east end, owing to the toughness of the rock—which was a hard quartzite. In the east end the heading was driven on the grade, and the enlargement afterwards "stoped" out by hand drilling, the miner standing upon an arched stage, movable on a track laid for that purpose. By this method the necessity of handling the material twice was avoided, though it caused constant blocking of the roadway built for the trucks running from the heading to the east end.

At the west end, and from the central shaft, the headings were driven in line with the roof of the tunnel, which was left complete as the heading progressed. This involved trucking by hand from the heading to the bench carriage where the cars were dumped

into what is called a "skip," which conveyed the material into the cars on the floor of the tunnel. This bench carriage is merely a platform the width of the tunnel, raised to a level with the heading, and movable on a track laid on the sides of the tunnel. By using this carriage, the miners were enabled to work at the enlargement while the work at the heading was progressing—the cars to receive the material taken from the enlargement being run under the bench carriage to where the work was going on. The carriage was run back out of the way when a blast was fired.

In driving the headings where the rock was hard and tough, from 8 to 10 holes were first drilled in the direction indicated in Fig. 4, Plate I., four or five being made on each side, one above the other. They were then charged with nitro-glycerine or dynamite, and all exploded at once. In this way 25 to 30 tons of rock were frequently removed at a single blast. The holes varied in depth from 5 to 13 feet, and were 1½ inches in diameter. Where the rock was softer, as in the east end, 25 to 30 holes, from 30 to 40 inches deep, and 2 inches in diameter were drilled, and charged with cartridges of gunpowder, which were all exploded together. It is said that an advance of three feet was frequently made in this manner, with a single discharge.

The headings were driven and much of the enlarging was done with the Burleigh Rock Drill. These drills in each heading were mounted upon two carriages standing side by side, with a space of about six feet between them; each carriage supporting 5 or 6 drills, though seldom more than 4 (8 in all) were in motion at the same time. They make from 200 to 300 strokes a minute with a pressure of 60 lbs. per inch. When a blast was to be fired, these carriages were run back out of the way. The drills were driven by compressed air; those in the east end heading being supplied with air compressed by the water power of the Deerfield dam, and conveyed to the drills in cast iron pipes. At the west and central shaft headings the air for working the drills was compressed wholly by steam until the bench at the junction east of the central shaft was removed. After this the pipes in the eastern section were connected with those in the central section, which had been theretofore supplied only from the steam compressors at the top of the shaft, and the drilling was acomplished with pressure created at the Deerfield river wheel-house which was three miles distant.

The material excavated at the bottom of the shaft is raised to the surface by means of a double-lift. Small cars carrying about half a cubic yard are run between the headings and the shaft on a track laid for that purpose. The cars are run upon a track on the floor of the lift or cage, which takes them with their load bodily up the shaft to the surface, where they are run on a track to the dump, and tipped. The empty car is than run back on to the lift, which descends again to the bottom of the shaft. While this is de-

scending, the other lift, with its load, is raised by the same action of the machinery on the opposite side of the shaft, the two lifts passing each other back to back. In this manner a car comes to the surface once in 4 minutes. This same method was adopted at the central shaft, where as many as 160 car loads a shift or one every 3 minutes have been taken out. All the lifts used in the shafts are provided with safety catches which depend on a spring so fixed as to be compressed while the weight of the cage exerts a strain upon the cable, but should the strain be relaxed by the breaking of the cable or other parts of the winding machinery, the spring there acts upon stout iron teeth, forcibly projecting them against the guides along which the lift is moved.

The method adopted for putting in the brick arching through the soft material at the west end, was to push forward sheeting supported by timbers 25 ft. long and about 12 in. in diameter as the excavation progressed. These timbers were supported at one end by the brick arch already constructed, and at the other by timber work in the manner indicated in (Fig. 1, Plate II.). A section of 20 ft. of arching was then turned inside of this timber work. As soon as this was completed another set of timbers was put in, with the ends of them resting upon the arch between the ends of the preceding set, when another section of arching was built. Counterforts were put in at every junction of the timbers, and also where there was much caving on the sides, in the latter case the spaces between them were filled so as to equalize the pressure. Some few counterforts were put in quite close together where the filling was not needed.

The direction of the tunnel was first determined by permanent stations built upon the two summits, and the line extended upon the promontory in front of each end. From the latter it was carried down to the level of the tunnel. At the central shaft the line was transferred from the surface to the grade of the tunnel, by determining two points A and B (Fig. 2, Plate II.), in the line of the tunnel and ~~100~~ feet from the shaft; at each of these points a transit was placed. The points C and D were then selected and a horizontal vernier with an upright similar to a compass sight placed at each. The vernier being used to detect the lateral motion of the upright. An upright with a movable arm was also placed at both E and F, and directly under these arms and near the bottom of the shaft, two double verniers were placed horizontally. Each of these verniers consisted of a square plate graduated on two adjacent sides, with an opening in the middle large enough to allow the free oscillation of a wire passing down the shaft and through it. On the top of this plate there are two sets of slides, the two of each set so arranged as to move toward each other, and in a direction perpendicular to the motion of the other set. Two wires with weights attached were now passed through the opening in the uprights at C and D, and over the movable arms at E and F, down the shaft and

through the opening in the double verniers. The openings in the uprights at C and D were then brought accurately into the line A B with the transits, and the movable arms at E and F adjusted till the wires also came into this line. The amount of oscillation was now determined by the double verniers, and the slides moved so as to clamp the wires in a vertical position. Two points at the bottom of the shaft were thus obtained, by means of which headings were started toward the east and west.

The junction made in December 1872, between the heading advanced toward the east from the central shaft and that driven from the east end, afforded the means of testing the accuracy of the method of transferring the line from the surface, to the bottom of the shaft, as well as that employed in prolonging this line.

The following is the account as given by the Engineer of the tunnel in his report for the year 1872. "The results obtained show these lines to have been traced without deviation exceeding the fraction of an inch; although the larger one has been extended for a distance of 11,274 feet, or about two and one-eighth miles, from the eastern portal, and for the other, 1,563 feet long, the interval between the plummet lines, carried down to the depth of 1,028 feet below surface in order to establish the initial direction at the bottom of the shaft, was but twenty-three feet."

The final junction, or the junction between the heading from the west end, and that from the central shaft advanced in a westerly direction, was not made till November 27th, 1873, or nearly a year after the junction above mentioned was made. The work on both of these headings was continued till by the Engineer's measurement there was an interposing wall of only 16 feet in thickness between them. A hole was first drilled through from one heading to the other, after which, twelve more were drilled in each heading in the direction indicated in (Fig. 5, Plate II.). These latter were then charged with 150 lbs. nitro-glycerine, and the wires passed from the cartridges in one heading, through the connecting hole to the other, and all the cartridges exploded simultaneously. The effect of this explosion was so great, that after it, they found an opening connecting the headings five feet high by three feet wide. The following extract from the report of the Engineer for the year 1873, shows the accuracy with which the lines joined at this time had been prolonged, and also mentions other matters of interesting engineering detail. "A result showing similar exactness in the working lines in the western division of the tunnel, has been afforded by the meeting accomplished November 27th, 1873, at a point distant 2,056 feet, or little more than three-eighths of a mile west from the central shaft, and 10,138 feet, or a little more than $1\frac{9}{10}$ miles from the west end. At this meeting point, the shorter working line tested by the determining points of central shaft and east end was known to be in exact position; and the line of $1\frac{9}{10}$ miles was found to have deviated only by the amount of nine-sixteenths of an inch.

* * * * * * * * * *

The preliminary determination of length was first made by a measurement from end to end of the tunnel, carried over the summits of the mountain. The ultimate establishment of actual length, made by measurement through the tunnel, completed since the entire way was opened in November last, has been found to differ from the preceding only by the amount of $\frac{85}{100}$ of a foot, being in the proportion of only three one-thousandths of one per cent. of variation in the distance of $4\frac{3}{4}$ miles. Preliminary levels were carried respectively from east and west end over the respective summits, to determine the elevation of the central shaft.

Since the opening through the tunnel affords an opportunity of connecting the working levels, it is found that their determination of the exact elevation of the west portal varies only by $2\frac{3}{100}$ of a foot from the result of the preliminary levels."

During the prosecution of this work, the principal explosives that have been used are gunpowder, nitro-glycerine, dynamite, and the mica powder. The former was employed where the rock was soft as in the eastern section, the nitro-glycerine being used to break hard and tough quartzite in the western section. In the latter part of 1872 dynamite was substituted for nitro-glycerine on account of its cheapness, the second quality being principally used. After a number of trials, it was found necessary in order to insure perfect combustion, to use a small cartridge of nitro-glycerine, or dynamite No. 1, to explode it. This renders its use so expensive and inconvenient, that they were induced to try Mobray's mica powder, another compound of nitro-glycerine which was invented about this time. This is made by cutting the ordinary sheet mica into small pieces of about an eighth of an inch in diameter, by passing it successively through two sets of revolving knives, the second set reducing it to the proper size; the dust is then taken out, and the remainder mixed by hand with nitro-glycerine, the first quality being 33 per cent. of mica and 66 per cent. of nitro-glycerine, only 40 per cent of the nitro-glycerine is used in the second quality, the remaining 60 per cent. being mica.

After trying the mica powder for a month, it was found that an equal quantity of rock could be excavated with it and at a much less cost, than with the mixture above mentioned. It was accordingly adopted and is now extensively used. Nearly all the exploders at present used in the tunnel are manufactured by C. A. Brown and Brother. The electric machine employed for firing them is what is known as the Smith Frictional Machine.

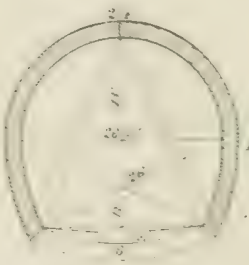
The pumps used to lift the water through the shafts were the ordinary Cornish pumps. The largest one, which was in the central shaft and 12 inches in diameter raised the water in four lifts of 250 feet each, there being a tank or reservoir to receive the water at

the top of each lift. The pump-rod was composed of timbers 12 inches square joined to each other so as to form a continuous piece, extending from the surface to the bottom of the shaft, to this, the plungers were attached and the water was forced upwards from the tanks at each downward stroke of the piston. The pump-rod weighed when put in 27 tons. The question of ventilating the tunnel has not as yet been sufficiently considered, to determine what means will be necessary to keep it clear of smoke and foul air. At present the current which is constantly passing through the tunnel from end to end seems sufficient. This as far as has been observed passes from west to east in the morning and early in the afternoon, after which it changes to the contrary direction for the remainder of the day. The central shaft it is thought, retards rather than assists this current, as a heavy fog is sometimes observed in the tunnel at the foot of the shaft.

The excavation of the tunnel at present is nearly completed, there remaining only a short bench to be taken out west of the central shaft before it will be full size from end to end. The brick arching at first contemplated has been completed. It has however, since become necessary to build it at intervals throughout the tunnel, so as to cover all places where the roof has been shattered during the excavation and thus prevent accident from falling masses; this will of course materially increase the cost, as well as delay its completion. Notwithstanding this delay, it is now estimated that in a year from the present time, the track will be laid and the tunnel ready to form the connecting link between the East and the great West. Its cost when completed, will probably exceed ten millions of dollars.

HOOSAC MOUNTAIN TUNNEL

SECTION ON LINE OF TUNNEL



Section of Tunnel in
Brickwork
Scale 24ft to 1 inch



Fig. 2.

Fig 3.

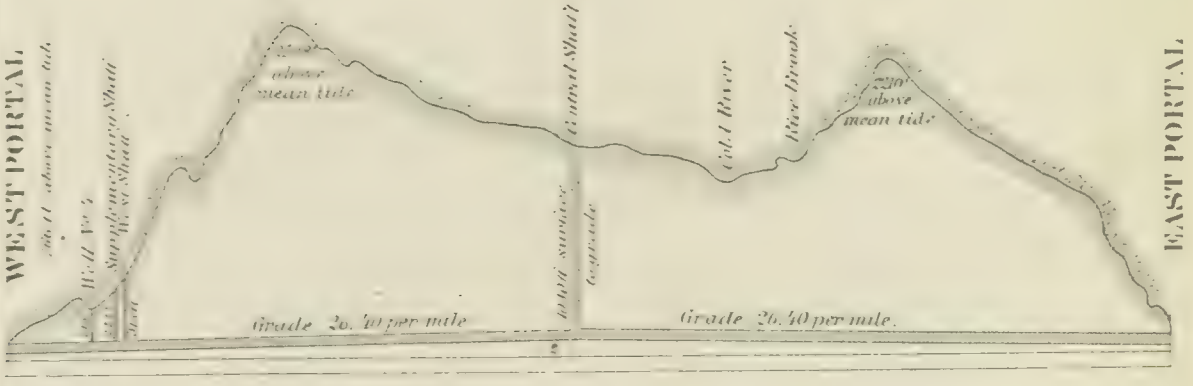


Fig. 1.

Horizontal Scale 3920 ft. to 1 inch

Vertical Scale 980 ft. to 1 inch.



Fig 4.



Fig. 5.

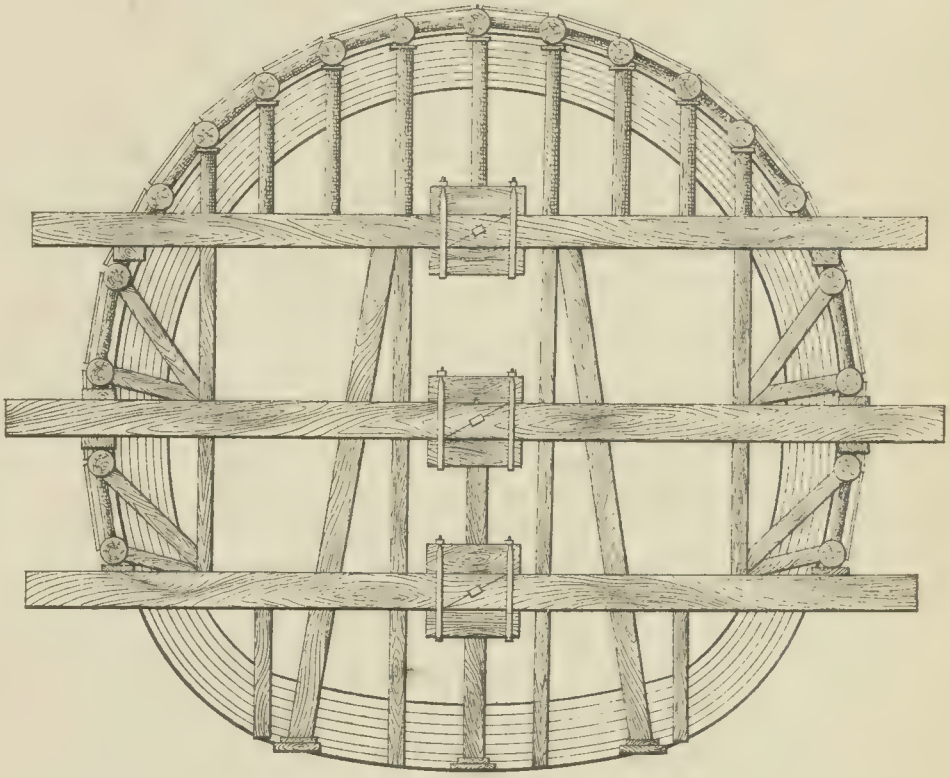
Scale 24 ft to 1 inch

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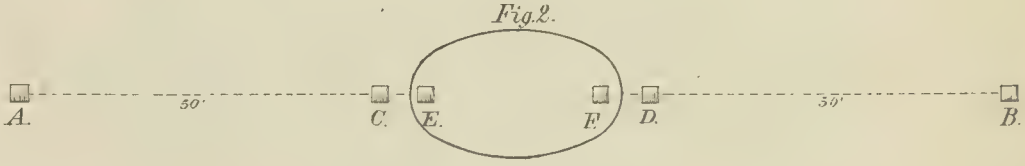
TIMBERING IN SOFT MATERIAL
in
EXCAVATION FOR BRICK ARCH
of
WEST END OF HOOSAC TUNNEL.

Fig. 1.



Scale 8 Ft. to an Inch.

Fig. 2.



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JETTIES

FOR

HARBORS AND RIVERS.

READ BEFORE THE ESSAYONS CLUB OF THE CORPS OF ENGINEERS,

AUGUST 10, 1874;

FROM

LIEUT. JAMES B. QUINN,
CORPS OF ENGINEERS.

NO. XXXVI. PRINTED PAPERS.

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JETTIES FOR HARBOR AND RIVER IMPROVEMENT.

A paper read before the "ESSAYONS CLUB" of the Corps of Engineers, on August 10th, 1874, from Lieut. James B. Quinn, Corps of Engineers.

There is probably no question presented for the consideration of the Engineer, fraught with greater difficulties of solution and surrounded with so many conflicting circumstances of opinion, as that of Harbor and River improvement; circumstances of location and the varying conditions in the nature of the improvement sought, render the adoption of any fixed system impossible of general application, and give use to a multitude of plans and expedients, to meet the various conditions that may engage the engineer's consideration.

In the selection of any plan for a required improvement, the choice is necessarily restricted to those, which may be possible with, the means disposable and the character of the materials available, conditions, which frequently leave the engineer without the advantage of a tried precedent, and force him to rely entirely upon the effects of his individual ingenuity; under such circumstances it does not appear possible, however well considered the plans finally adopted may be, that all the conditions, existing or prognosticated, will be provided for, but on the contrary, that some most important shall in all probability be overlooked, or necessarily neglected in providing for the most urgent.

It is therefore questionable, whether the perplexities of the problem should be further augmented, by the contemplation of the possible future improvements of a more permanent character, to form a part of the construction under consideration; particularly when no certainty can exist, regarding the probable designs or differences of opinion which may influence those who may have charge of the work in the future.

If the engineer possessed the power to control the operations of future directors, of any work he may have projected, there would then be some excuse for the popular inclination, to expend large sums in the elaboration of projects for permanent improvements, which are, no matter how eminently calculated to meet the requirements of the present, subservient to future alterations of circumstances and conditions.

If any considerations of future possibilities must influence the engineer, it would appear to be advisable to limit them to those reasonably probable in the immediate future, and so shape his course, that his constructions, while answering all the requirements of the present, may not restrict the radical adoption of other plans, which circumstances may render more advantageous.

There are it is true constructions which require to be built in a most substantial manner, and must therefore necessarily possess a somewhat permanent character, but at the same time it is believed, a far greater expense is incurred in such constructions, than the circumstances of the case warrant, for the very reason, that the idea of *efficiency*, is burdened with that of *permanency*.

Many artificial harbors in the old world, built in a supposed permanent manner, have proved to be entirely of inadequate size, or from other vital alterations in circumstances, unsuited to present conditions, and will therefore require expensive alterations; while improvements at the mouths of rivers, have for similar reasons, been either abandoned or replaced by entirely different constructions; while in our own country, a review of the system of improvement of harbors and rivers, as generally practiced on the great lakes, affords a familiar field of illustration, of the necessities at present existing, for some plan of improvement, that, while answering the requirements of the different localities, will at the same time be, *economical in construction*, *easy to maintain*, *and readily removed when required*.

By refering to Col. Houston's paper upon the subject of "Harbors of the Great Lakes," we learn that the harbor improvements upon the great lakes, "consist in making a channel of proper width and depth from the deep water of the great lake, to the deep water of the river, lake or artificial basin inside, and the construction of works for the maintainance of this channel."

That, "the works executed for protection of the channel are generally parallel piers, extending from the shore at a distance apart equal to the width of the channel." That, "the effects of these piers, extending from the shore, is to arrest the drift of sand and shingle, and cause an accretion, which necessitates the extension of the piers from time to time. This accretion is greatest on the side of the prevailing winds." That the distance between the piers is not sufficient, and he considers their parallelism objectionable. That the construction of the piers is attended with considerable risk. That "the rapid increase of the lake commerce is such, that there is not time for the construction of such elaborate works as we find in the old world." And finally, that the piers in salt water would have to consist of masonry or loose stone.

In contemplating the many defects the system of lake harbor improvements is in-

dicated as possessing, the inference naturally occurs, that if the piers had been of less elaborate construction, important alterations would be possible without too great a sacrifice, and the maintainance of a defective system, at a constantly increasing cost, might have been obviated; and this inference is strengthened by farther contemplation of the fact, that the sole indicated purpose the jetties serve, is to preserve the artificial channel from being filled up by sand, borne by the littoral currents.

Since the sand borne by the littoral currents appears to be the aggressive element, a proper understanding of the manner in which this sand is moved by the currents, will be of importance in determining the character of the defense; were we able to see exactly the way the currents transport the sand, an explanation would be comparatively easy; but unfortunately the sand diffused throughout the water allows an inspection of results, only after the water has become tranquil, and deposited all the material it held temporarily in suspension. There is good reason, for believing however, that the action of currents of air upon sand, bears some analogy to that of water, in fact as far as my observation extend, the phenomena are identical in some respects.

Whenever the wind sweeps the sand before it, hillocks are formed where even slight obstructions cause the lodging of the flying sand, dunes often of slight elevation, but frequently high hills, are thus formed.

When the wind blows with sufficient force, we can by depositing something upon the ground, not only witness their formation, but verify by actual experiment the theory of this formation. If we construct a palisade perpendicular to the direction of the wind, the current of air which strikes against this, instantly rebounds, forming an eddy the diameter of which is always proportionate to the height of the palisade, the velocity of the air being thus reduced, the sand carried by it is deposited on the near side of the obstacle, and this action is continued until the crest of the dune and the ramp of sand is on a line with the top of the obstruction. Then the sand borne by the wind, is no longer deposited as before, but is carried across the ravine formed in front of the palisade by the gyrations of the air, and deposited on the farther side of the obstacle, the little ravine is closed in time by the sand rolled up the inclined surface by the wind, and eventually a dune is formed, which continues to increase in height and extent, by the addition of sand to the farther slope.

A certain arrangement of the particles of sand borne by the air also exists, the lighter particles being transported farther, from being carried at a greater altitude, while the heavier particles are rolled along the surface.

The formation of a sand dune, presents certain features, identical with those produced when a crib is sunk upon the lake bottom, within the limits of the littoral currents, the

current of water being arrested by the obstacle, is deflected, partly upwards, and partly downwards, the latter component forming a whirlpool, that excavates a trench along the bottom of the crib, and depositing part of the excavated material in front, with that dropped by the arrested current.

The crib is thus undermined, in a degree depending upon the strength of the littoral current, and by sliding into this trench, the crib will actually advance against the current, a movement that is farther augmented, by the vibratory motion imparted by the waves.

The current does not give up all the material it held in suspension on rebounding, but being unable like the wind to mount above the obstacle, it is constrained to make its escape by passing around the end of the crib, where a further deposit takes place, in the eddy formed there. It is possible to extend the piers beyond the point where this transverse current will contain sand in suspension, and for the time, this deposit at the end of the pier ceases, but the sand being banked up in the angles formed by the piers and the shore, tends to increase the transverse current, and the sand held in suspension by it is also increased in quantity, and carried further, necessitating further additions to the ends of the piers.

It is probable the sand laden current, does not extend much beyond the 12 ft. curve, as the piers at Sheboygan, and Manitowoc, when built out to this curve, had no deposit for some time at their ends, and probably beyond the 6 ft. curve, the *waves* contain no sand, since during severe storms, the water outside this curve appears perfectly clear. It is quite likely that most of the sand borne by the current, is carried but a slight distance from the bottom, or mainly rolled along the bottom, the principal matter coloring the water, being very fine sand or clay.

Beyond the 6 ft. curve, it is my opinion, that in order to effectually arrest the sand, it is not necessary that the jetties should even extend to the surface of the water; neither does it appear necessary that the jetties should extend above the surface of the water, to insure a tranquil anchorage in rear of them, for the Florida Reefs, having 6 ft. of water on their crests, so moderate the force of the waves, as to afford secure harbors in rear of them. Thus considered nothing is apparently so well adapted to meet the requirements of the problem, as jetties formed of one or more rows of gabions, of large size, with close plank bottoms, and filled with the material dredged from the channel, or cast into them from a trench dug on the outside, a short distance from them. (See illustration).

That they can be arranged in a variety of ways, or built of different sizes to suit the different requirements, or covered inside or out with cement, to prevent the escape of sand, if this material is used to fill them, is suggested at once, that they may be fastened together in sections, be towed to the proper spot, and placed with ease and certainty at little cost, must be apparent.

From not being exposed to the full force of the waves, on account of not being within a distance of the surface, more than just necessary to upset the waves, and transform them into breakers, their stability is easily insured, and by covering the exterior slope with a fascineage, ballasted with stone, any degree of desired permanence may be secured.

Possessing a certain degree of pliability, no preparation of the surface upon which they are to rest, will be required.

If it is possible the jetties may be undermined, by fastening the gabions upon a mattress of fascines, which may be made to project on either side, and be properly ballasted with stone, in such a manner as to prevent its rising, no such action can occur.

The construction of the gabions may be continued during the inclement seasons, and the rapid manner in which jetties can be constructed with them, would in any season render possible a protection, that could only be obtained in several, by means of cribs or piles.

And for constructions in salt water, where the ship-worm abounds, they appear to afford the only economical system of construction, for the preservation of harbor entrances.

From what proceeds, it must be apparent, that the best position of the jetties to effectually arrest the drifting sand, is perpendicular to the direction of the current that transports it, but the prolongation of a jetty, in a right line, perpendicular to the shore, causes an accretion in the angles formed by the jetty and the shore, that will soon exercise a material influence in the deflection of the littoral current, and materially increase the transverse current, or current flowing along the jetty, and since this latter current, is the one that deposits the sand at the outer end of the jetty, thereby necessitating expensive additions to its length, but little reflection is necessary to produce the conviction that the prolongation of a jetty in a right line perpendicular to the shore, or proceeding from the shore in a curved or broken line, having its *convexity outwards* must be an erroneous disposition to economically effect the object sought; manifestly the advantage of having the jetty always perpendicular to the direction of the littoral current, can only be obtained, by commencing perpendicularly to the shore, and proceeding outwards in a curved line, having its *concavity on the side toward the littoral current*, and thus proceeding, till the extension is in the direction of the prevailing wind, when farther prolongation should be in a straight line. (See illustration).

The degree of curvature will depend upon the locality, but no precise rule can be given, nor is it believed necessary, farther than the general one, that the jetty shall always be about perpendicular to the littoral current, as it may be modified by the accretion which may take place in the shore angle, of which some idea may be formed, from the condition of the bar at the mouth of the river, or the extent of the accretion, at points near by, which have been improved by jetties.

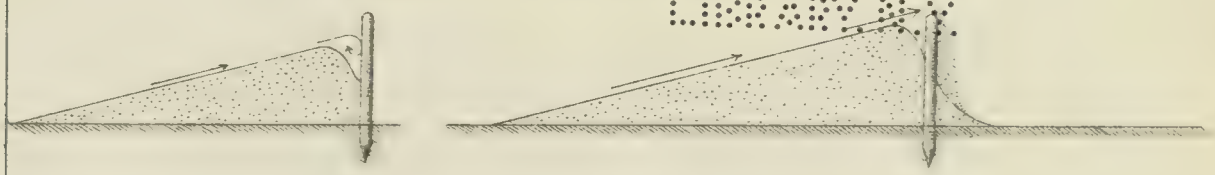
The drifting sand having been disposed of, the position of the breakwater for the protection of the anchorage next requires consideration. This may join the jetty, at a point necessary to afford the required room, or depth of water desired within the harbors, and proceed in a right line perpendicular to the direction of the prevailing wind, until the required amount of protection is secured, when the curved return toward the shore may be commenced, and continued until the direction is that of the prevailing wind, where an opening of five or six hundred feet in width, should be left, for the entrance; after which the continuation of the enclosing jetty may proceed to the shore, in any line desired, provided no littoral current will flow against it, otherwise it should have a similar curve to that of the first jetty.

The excavation of the channel across the bar, may be proceeded with as soon as the construction of the breakwater will afford sufficient cover, the system of construction obviating the necessity of, a revettment for the sides of the channel.

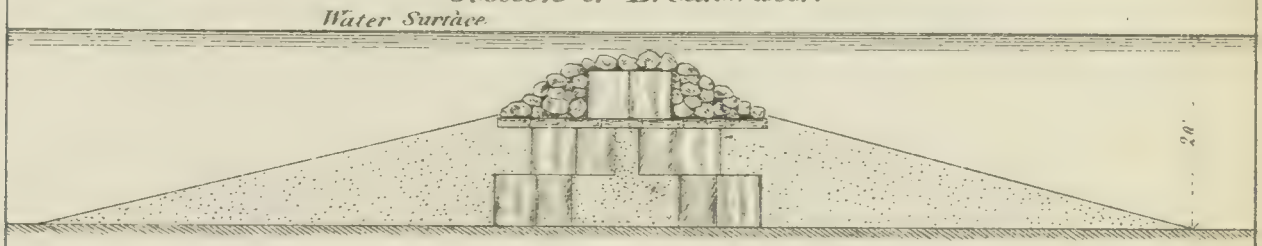
Note.—Since no system of jetties appears to be applicable to the improvement, of the entrances to rivers, which form thin bars with their own sedimentary material, the foregoing remarks are not intended to apply to such species of Harbor and River Improvements.

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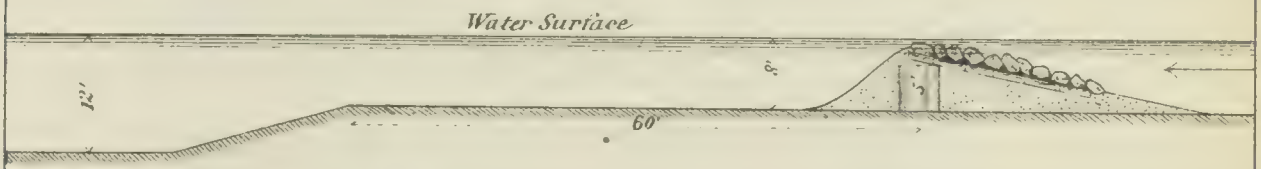
Formation of Sand Dune



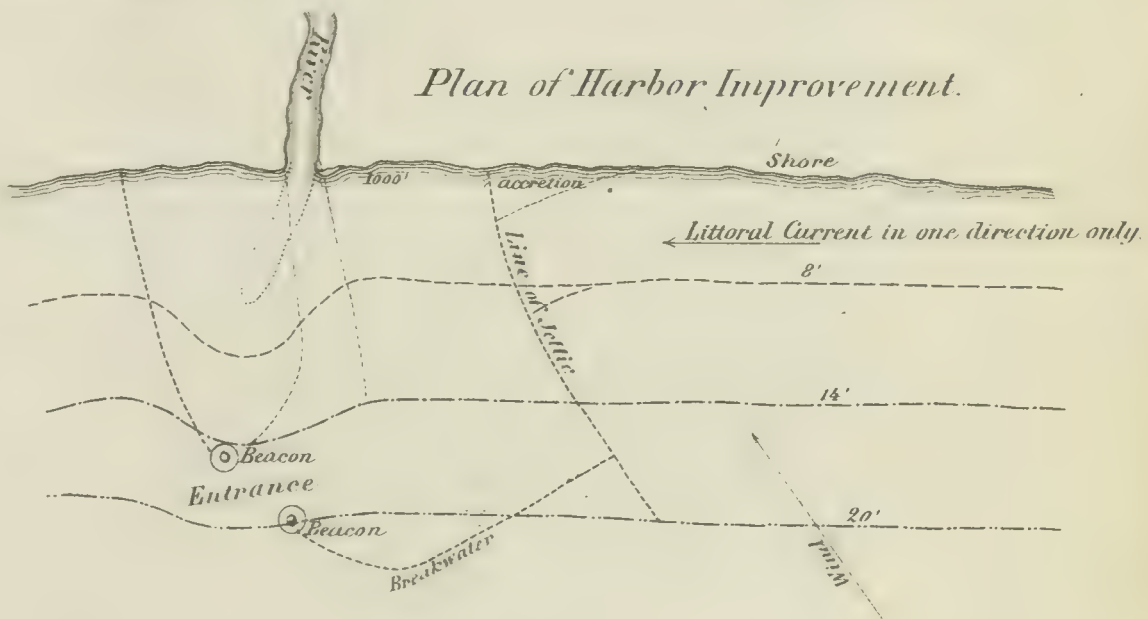
Section of Breakwater.



Section of Jettie.



Plan of Harbor Improvement.



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REPORT

UPON

THE DOCKS OF NEW YORK CITY.

READ BEFORE THE ESSAYONS CLUB OF THE CORPS OF ENGINEERS,

JUNE 3, 1874;

BY

LIEUT. BENJAMIN D. GREENE,
CORPS OF ENGINEERS.

NO. XXXVII. PRINTED PAPERS.

Printed on the Battalion Press.
Sergt. Carmichael & Pvt. Wade, Printers.

NOTE.

This paper was prepared in compliance with instructions issued from the Headquarters of the Battalion of Engineers—under approval and direction of the Hon. Secretary of War and the Chief of Engineers—directing each officer of the Battalion to visit and examine, during the winter suspension of drills, some specified public work or manufacturing establishment. By request it was read before the Club; and being considered to contain information of interest to Engineer officers, it was ordered to be printed.

This note is prefixed by a vote of the Club, in order to explain the peculiar character, and necessarily limited scope of the paper.

THE DOCKS OF NEW YORK CITY.

A paper read before the "ESSAYONS CLUB" of the Corps of Engineers, on June 3rd, 1874, by Lieut. Benjamin D. Greene, Corps of Engineers.

The plan of docks now under construction in the City of New York was adopted in 1871. It is embraced in the general system of protecting the river front by a permanent river wall of masonry, carried out from the present bulkhead line a sufficient distance to make a river street 250 feet wide on the North River, and 200 feet wide on the East River, with such exceptions as the proper location of the line introduces. From this river wall piers will project of varying dimensions to meet the requirements of commerce. These piers it was originally proposed to build for the most part of preserved wood, and of a more durable and substantial character than are ordinarily built.

This course was recommended on account of the cost of masonry and iron, though provision was made for the erection of a few of these latter materials, and they will be extended when regarded expedient. The considerations which determined this general plan are stated by the Engineer in Chief as follows. * "For a well sheltered port, where the water front is extensive in proportion to the commerce, where the bottom shelves rapidly, and the daily variations of the tide are not great, the simplest and most appropriate form of construction is a quay or river wall, so located, that the largest vessels can float alongside of it at extreme low water. Where the bottom shelves away gradually, it becomes necessary to extend piers so far out, that the water near the ends will be deep enough to float vessels. Piers are also necessary in cases where, even when the water deepens very rapidly, it is necessary to accommodate a large commerce along a comparatively limited water front, as well as when it is desirable to afford protection against a rapid current, floating ice, etc."

A topographical and hydrographic survey of the entire shore line of the island was made, during which 50,000 soundings and 5,500 borings were taken, most of the borings

* Report of Gen. McClellan 1871.

being continued to bed rock. The borings were made from a scow, by forcing down a tube by compressed air, and by the Woodcock borer. The first class for depth, the second for strata thickness. There was found along the new bulkhead line a depth of water of from 5 to 20 feet, soft mud to an average depth of 23 feet, then tenacious mud of varying depth, 3 to 30 feet, then alternating strata of sand and gravel with sometimes clay, varying to 30 feet in depth to the bed rock.

One sample taken at random from the collection is as follows:

Material.	Thickness.
Coal ashes	5 feet.
Dock mud	13 "
Sand and mud	3 "
Sand and shells	10 "
Red sand (coarse)	3 "
Red gravel (feldspar and quartz)	6 "
Gray sand	2 "
Clay	1 "
Clay and vegetable matter	1 "
Gray sand	1½ "
Gravel (feldspar and quartz)	1 "
Gravel (course quartz plenty)	13 "
Gravel (fine)	1 "
Red sand	2½ "
Clay sand	½ "
Red sand with mica	7 "
Bed rock—mica schist.	70½ feet.

It was decided to give the water along the new river wall a depth of 20 feet. This would allow a slope of $\frac{1}{2}\frac{1}{0}$ to the depth required, and still with piers from 500 to 600 feet in length admit the largest vessels within the slips. In the location of the river wall and pier head lines, great care was taken that they should nowhere reduce the cross section of the river to an area approaching its controlling section, thus avoiding any diminution of the scouring effect of the tide. The supports of the piers were designed to present the least possible obstruction to the current, which had been a great defect in the old piers, and in connection with the position of the sewer outlets had caused troublesome deposits. While not thought advisable to construct a longitudinal sewer adjacent to the river wall, it is intended that the outlets of sewers piercing it shall be at or near the pier head.

With reference to the general sections and materials for the bulkhead wall, the following determination was made. Height of wall 24 feet, base width 17 feet 6 inches, face batter 2½ inches. Two offsets on back of 3 and 2 feet, coping granite 4 feet wide and 2½ feet rise. The wall to within 2½ feet of low water is constructed of 2 courses of concrete blocks, each having rise of 6 feet, 2 rows of blocks forming each course. Above the level of the béton blocks the wall is constructed of concrete laid in mass, faced with

fine cut granite ashlar masonry laid headers and slutchers in each course. The face batter has been changed to one inch from the béton blocks up. This wall weighs about 24 tons to the linear foot, and gives 22 lbs. pressure to the square inch upon the foundation, throwing out the consideration of water. The concrete blocks used under water are of proportions 1, 2, and 5, Portland cement, sand, and broken stone of size to pass 2 inch ring. The sand used is "Northport" sand. The concrete for the blocks is mixed in the usual way by hand, shoveled into the molds and rammed thoroughly. The molds have been removed after two days, from that to seven is usual time. The blocks are used in the construction after 2 or 3 months exposure to air. It is said they stand a pressure of 1600 lbs. to square inch, and weigh 150 lbs. to the foot. They weigh from 25 to 50 tons and are handled by the large floating steam derrick. They cost about $\$ 11\frac{50}{100}$ per cubic yard. For the molds used in the manufacture of these blocks, a long platform is prepared having cleats fastened to it by screw bolts at proper intervals. These hold the bottoms of the molds. They are secured at top by screw bolts, and two sides lock the others. The sides of the molds are made of 8 inch square scantling faced with $1\frac{1}{2}$ inch plank.

At pier 1, North River, a river wall, boat landing and arched pier of masonry on béton blocks has been built. The foundation here is on solid rock, which was found at a depth of 30 feet below low water mark. For the river wall there was prepared a rip-rap foundation up to fourteen feet of low water mark. For the piers of the arches concrete in mass and in blocks from the rock up. For the wall the mud was removed nearly to the rock, and the stone thrown in until the foundation was brought to the proper height. It was rammed from the centre outwards, leaving a wide margin untouched at crest of the slope. (See Fig. 1.) A bed of small stone was put on, and approximately leveled by divers. This was covered by a bed of concrete about 2 feet in thickness. This concrete was put in with a chute, and was confined by oak plank $2\frac{1}{2}$ inches thick, which were supported on blocks of concrete placed properly by divers. The plank were held upright by guide irons projecting above the béton blocks. The top edge of the planks were put at the level of bottom of first course of blocks. After the work was brought up nearly to low water mark, it was loaded double weight and allowed to take a permanent form before the superstructure was added; it settled about 7 inches in less than as many weeks.

The mass concrete used under water, is of proportions 1 2 and 3 or 4, (the latter being considered rather better) of same materials as the blocks, except that the sand is beach sand from Staten Island. The mass concrete for the pier foundations was placed as follows. A crib of proper size, (see Fig. 2) 60 feet long, 12 feet wide and 4 feet high was made so as to admit sheeting plank 2 inches in thickness around its entire circumference. This was swung into place by a derrick, and supported at proper height above

rock by spuds or blocks. The sheeting plank were run through to the rock. The concrete was put in with clam shell and ordinary buckets, and leveled at proper reference by the divers. This reference was about 22 feet below low water mark. A course of béton blocks is next put on, these blocks being 13 feet long, 8 feet wide and 4 feet thick. Upon this is placed a row of béton columns 14 feet in length, $7\frac{1}{2}$ and 10 feet in breadth and $5\frac{1}{2}$ feet in thickness. This brings the work to within 3 feet of mean low water mark. All the large blocks used on the work are suspended, while being removed, by heavy chains, which pass entirely around them in grooves of semi-circular cross section, and 14 inches diameter. From the tops of the columns the granite masonry of the arches is carried. It begins with the springing stones, granite blocks 4 feet in height and 3 feet 6 inches in breadth. The arches spring from a line about 2 feet below low water. Slight differences of level in the tops of the piers, are adjusted on the under surfaces of the springing stones which are left undressed for six inches in thickness. The arches are circular, radius $10\frac{35}{100}$ feet. The back filling is concrete in mass, which forms the top surface of the pier. Vertical grooves are left in the face of the piers for the insertion of timbers as fenders. It is doubtful if they will be found necessary. It would seem more to the advantage of the vessel than the pier, that fenders should be out.

It is suggested that the piers might well be built of one solid mass of concrete, on the other hand it is proposed to cut down the blocks now used, because they require special machinery to handle them.

The sections at foot of Christopher and Canal sts., are built on a pile foundation, the mud being some 70 feet in depth. The construction of the river wall was commenced by dredging a trench along its line, 80 feet wide at top, and nearly 20 feet deep. Eight rows of piles were driven in this trench about $2\frac{1}{2}$ feet apart between centers. These sustain the wall and bear a pressure of 150 lbs. to the square inch. They are driven with an 1800 lb. hammer, and yield $\frac{3}{4}$ of an inch under a final blow of 15 feet. Outside these piles are driven three rows at same distance, except the last row, which are nearer together. All these piles except this outer row are cut off 14 feet below water. The outer row are left a little higher. The space between the piles is filled to within 2 feet of their tops with broken stone. A layer of concrete is put on 2 feet in thickness. On this comes the first course of béton blocks. A concrete top is put over the outer piles resting against the extreme row, and the face of the wall rip-rap is thrown outside of all. (See Fig. 3.)

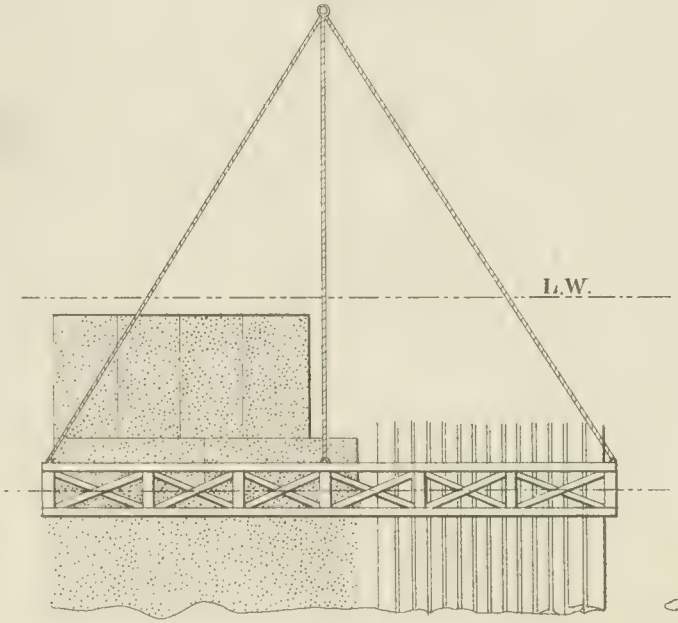
Two plans are proposed to retain the foundation from the pressure of the back filling. Piles driven in rear of the foundation, and stone loading the mud. The latter is probably the better one.

The piers at Christopher street are built on piles, driven in rows 8 feet apart, 5 feet

apart in each row. The pier heads are supported on built piles driven in rows 12½ feet apart. These piles are made of four pieces of scantling, each 60 or 80 feet long, 10 inches square, bolted together to form a pile 20 inches square. They are driven with a 3000 lb. hammer, and under a final blow of 20 feet settle 2 inches. All the piles used are of Virginia, or white pine, or spruce. The deck of the pier is formed of caps and girders of timbers 12 inches square, planked with 5 inch yellow pine plank. The piles are braced from low water up with 5 by 12 inch plank, screw-bolted and spiked. At pier heads the piles are braced by 5 inch solid oak planking, and iron screw-rods, also protected by a sheathing of boiler iron between high and low water. The snubbing posts are of cast iron, 18 inches in diameter at top with shell 1 inch thick, 16 inches diameter at bottom, shell 3 inches thick, with a projecting flange 1½ inch thick. The deck under them is double planked with oak plank. They are fastened to the deck and to the piles, by screw-bolts. The piers are from 550 to 600 feet in length, and from 60 to 80 feet wide. The docks between will be dredged to depth of 25 feet.

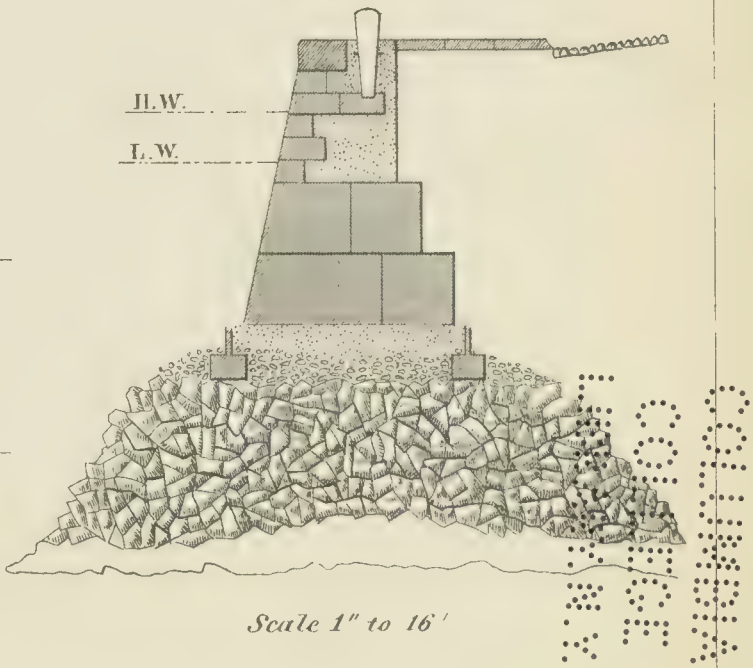
The original design of building with preserved timber was abandoned on account of the opposition of a member of the Commission. The method contemplated was the Seeley process. It would have added 60 to 80 per cent. to cost, probably 200 per cent. to durability.

Fig. 2.



Scale 1" to 20'

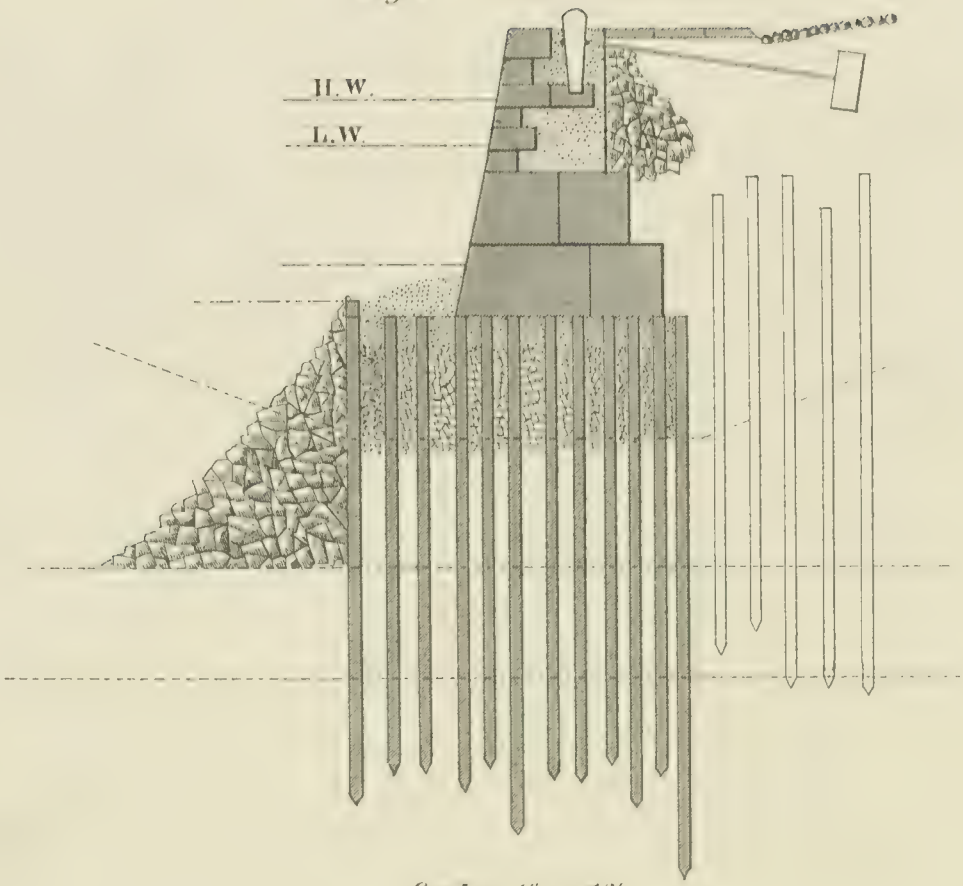
Fig. 1.



Scale 1" to 16'

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Fig. 3.



Scale 1" to 16'

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LONGITUDE

BY

LUNAR CULMINATIONS.

READ BEFORE THE ESSAYONS CLUB OF THE CORPS OF ENGINEERS,

MARCH 22, 1875;

BY

LIEUT. JAMES MERCUR,
CORPS OF ENGINEERS.

NO. XXXVIII. PRINTED PAPERS.

Printed on the Battalion Press.
Sergt. Carmichael & Pvt. Wade, Printers.

NOTES ON LONGITUDE BY MOON CULMINATIONS.

A paper read before the "ESSAYONS CLUB" of the Corps of Engineers, on March 22nd, 1875, by Lieut. James Mercur, Corps of Engineers

The method of determining the longitude of a place by moon culminations is at times the only one available which will give results at all approaching accuracy. Since in this method, errors in the assumed time of transit of the moon are magnified nearly thirty times in the resulting longitude, it is necessary to use all refinements in computation, in order to vitiate the result by no more than the unavoidable inaccuracies of observation.

The processes adopted in making these computations have been objectionable on the one hand from the rejection of too many small corrections, thus giving an uncertain result, and on the other from the laborious methods of determining and applying these corrections.

It is desirable to obtain a process which will give as great accuracy as the most laborious of these, combined with the minimum work in computation. To make more plain the principle which it is proposed to use in abridging the computations; let us suppose that the chronometer used has a rate of zero, and that the transit is in perfect adjustment in all respects; then the observations could be worked up, with perfect exactness, by the simple process of interpolating the moon's AR for the assumed longitude, finding the difference between this and that observed, and applying the correction for this difference by the use of the usual methods.

But when (as is almost invariably the case) the transit is not in perfect adjustment, the observations are not taken on the meridian, and the proper motion of the moon, in passing over the arc between the place where it is observed and the true meridian, together with its parallax in hour angle are the sources of the complexity which it is desirable to avoid in the computations.

In this latter case the line of collimation of the transit, at the time when the moon is on the middle wire, is directed to a point in the celestial sphere which is not upon the meridian of the observer, which will be designated by M, but upon that of some place

either east or west of him; let this meridian be called M″. Now the moon is observed when tangent to the middle wire of the transit; consequently the AR of the moon determined by applying no corrections to its instrumental transit would be its AR when on the meridian M′, which differs from M″ only by reason of the moon's parallax in hour angle. By using this AR and computing the longitude, the longitude of M′ would be obtained; to which applying the difference of longitude between M′ and M, which is equal to the error of the transit, when the moon was observed, diminished by the moon's parallax in hour angle, the true longitude of M will result.

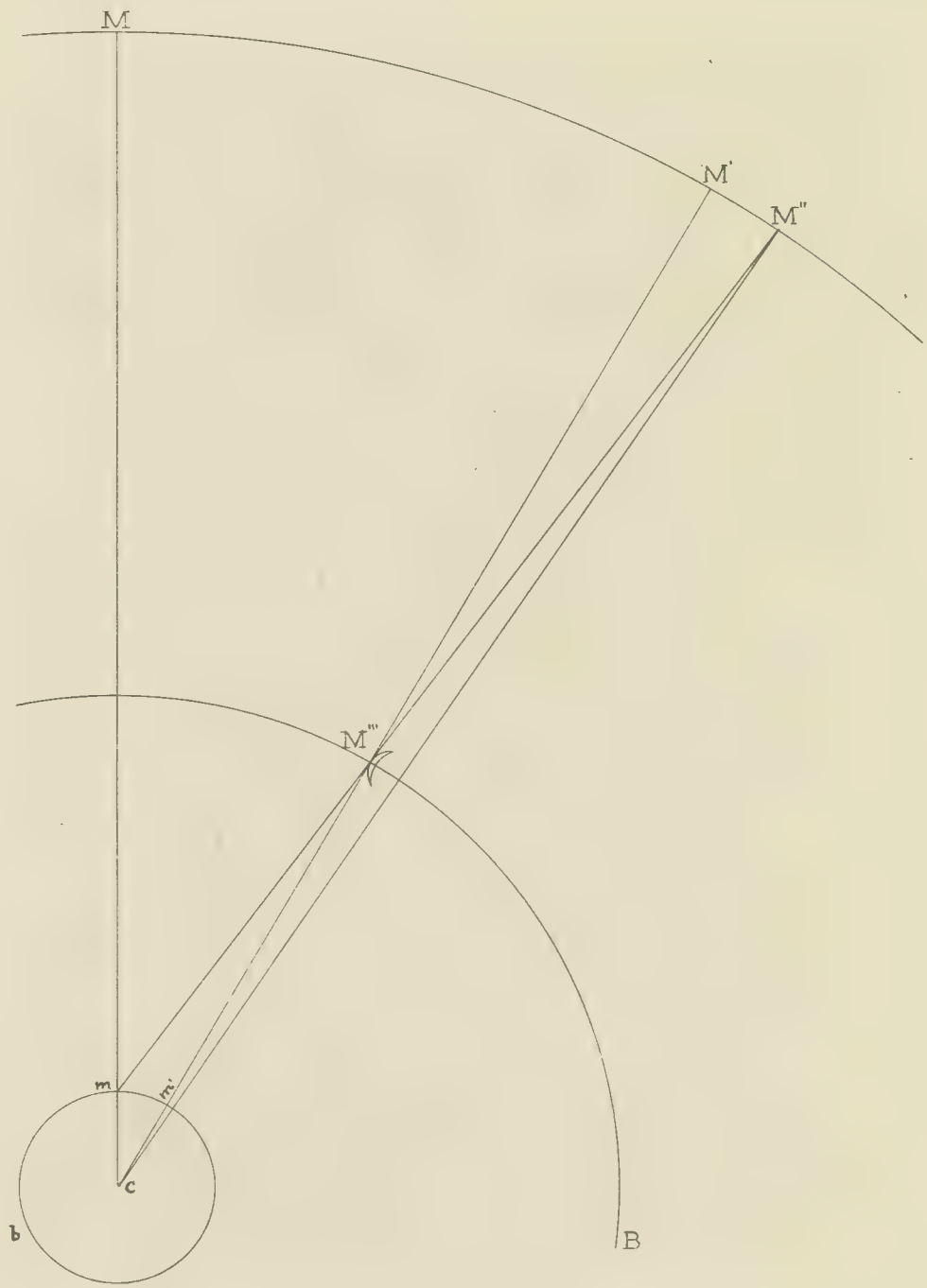
To illustrate this by a figure: assume the circle M M′M″ as the equinoxial, m m′ b as the equator, c M the observers meridian, c M′ the meridian M′, M‴ the moon at the time of observation. The moon will evidently be observed when it is upon the meridian M′ and this will be the meridian whose longitude is first determined. The error of the transit will evidently be M m M″ = M c M″ (m M″ and c M″ being parallel and intersecting on the celestial sphere) which exceeds M c M′ by the angle m M‴ c = M′ c M″ = the moon's parallax in hour angle; hence the final correction to be applied to the longitude M′ will be equal to the error of the transit at the moon's altitude diminished by the moon's parallax in hour angle.

If a star could always be selected of the same declination as the moon and differing from it but by 15 or 20 minutes of AR, the AR of the moon at the time of observation could be determined by simply applying, to that of the star, the difference of their times of transit; but this selection being impracticable, the same result is attained by taking, beside the transit of the moon, a complete set of observations for getting the clock error and unknown instrumental constants, and from these determining the corrections to be applied to each star and also to the moon, disregarding its proper motion entirely, and computing all the corrections exactly as if it were a star.

Each star thus corrected will give the same chronometer error, except as affected by errors of observation, and the mean of these will give the error to be used in the computations.

Now had one of these stars been of the same declination as the moon, it would have received exactly the same correction as that applied to the moon, and would have given the same chronometer error as that obtained from the mean of those observed; this chronometer error, plus the other corrections, applied to the observed time of transit would give the AR of the star at the time of observation, the same chronometer error, plus the same corrections, applied to the time of transit of the moon would give the AR of the moon which was sought; viz: at the time of observation, or when upon the meridian M′.

The method proposed for solving the problem comes directly from the foregoing dis-


M
M'
M''
M'''
m
m'
c
b
B

cussion and is as follows.

Having brought the transit into approximate adjustment, take the transit of one or both limbs of the moon and of enough stars to determine accurately the chronometer error and all the unknown constants of the instrument; reduce these transits according to the usual methods, treating the moon's limb however in all respects like a star; then correct the reduced time of transit of the limb by applying the chronometer correction deduced from the stars, and the result will be the AR of the limb at the time of observation.

When the arrangement of moon culminations as given in the British Ephemeris is used, the longitude may be found as follows:

Let L = the longitude sought.

l = the longitude of the meridian M′.

l′ = the assumed longitude.

m = the observed change in AR of the moon's bright limb between the meridian of Greenwich and M′.

m′ = the change between the meridian of Greenwich and M′, computed by interpolation.

V = the rate of motion in AR of the moon's bright limb when on the meridian l′, measured by the distance it would pass over in 12 hours of longitude if this motion were uniform.

I = the constant difference between the values of the independent variable in the tabulated AR of the moon = 12 hours of longitude.

e = the error of the transit at the moon's altitude.

p = the parallax of the moon in hour angle.

then $l = l' + I\,\frac{m-m'}{V}$

and $L = l' + I\,\frac{m-m'}{V} \pm (e-p)$

To find m′ and V Bessel's formula may be used for interpolating; it is as follows:

$$S = a' + t\,d_1 + \frac{t(t-1)}{2}d_2 - \frac{t(t-1)(t-\frac{1}{2})}{1.\ 2.\ 3.}d_3 - \frac{t(t+1)(t-1)(t-2)}{1.\ 2.\ 3.\ 4.}d_4 - \text{etc.}$$

In which a′ = the moon's AR at the next preceding transit at Greenwich.

$t = \frac{l'}{12\,h}$ = the fractional part of the constant difference I corresponding to the value of the term interpolated.

$d_1\ d_2\ d_3$ etc. = the consecutive orders of differences. Arranging this ac-

cording to the ascending powers of t it becomes $S = a' + A\,t + B\,t^2 + C\,t^3 + D\,t^4 + \text{etc.}$ Finding the values of the coefficients and omitting all terms involving differences of a higher order than the 4th.

$$A = d_1 - \tfrac{1}{2}d_2 + \tfrac{1}{12}d_3 + \tfrac{1}{12}d_4$$
$$B = \tfrac{1}{2}d_2 - \tfrac{1}{4}d_3 - \tfrac{1}{24}d_4$$
$$C = \tfrac{1}{6}d_3 - \tfrac{1}{12}d_4$$
$$D = \tfrac{1}{24}d_4$$
$$V = \frac{ds}{dt} = A + 2\,Bt + 3\,Ct^2 + 4\,Dt^3 + \text{etc.}$$
$$m' = S - a' = At + Bt^2 + Ct^3 + Dt^4 + \text{etc.}$$

The method of finding the transit error has been already explained.

The parallax in hour angle comes from the following formula.

$$p = e \sin \omega \cos \varphi \sin \delta$$

In which ω = the horizontal parallax of the moon.

φ = the latitude of the place.

δ = the declination of the moon.

p and e = as before.

If no approximate longitude is known it may be found from the formula. $l' = 12\text{ h.} \frac{m}{d_{,}}$.

When the American Ephemeris is used the following method may be adopted.

With the assumed value of l′ and the siderial time of observation find the corresponding Greenwich mean time; then with the hourly ephemeris of the moon interpolate the moon's declination and AR by using the changes in them, in one minute, as given in the tables. Take the difference between this interpolated AR and the observed AR of the moon's limb corrected for the siderial time of the semidiameter passing the meridian; divide this difference by the moon's motion in one second for the first correction for l′, and apply to the resulting longitude the correction (e—p)

The time, in seconds, of the semidiameter passing the meridian $= t_s$ may be found from the ephemeris or, when L is large, by the following formula. $t_s = \frac{sd''}{15\cos\delta(1 - 0.0166\,c)}$

in which $sd'' =$ semidiameter in seconds of arc.

$\delta =$ the moon's declination.

c = the number of seconds of AR passed over by the moon in one siderial minute.

Should it be desired to compare the observations upon the side wires with that upon the midwire, the reduction may be made, in case of the moon, by multiplying the equa-

torial interval of the wire by the ratio obtained by dividing the time of the semidiameter passing the meridian by the moon's semidiameter, both reduced to seconds of arc, and adding this result to the time of passing the side wire; or, time of passing mid-wire = time of passing side wire + equatorial interval of that wire multiplied by $\frac{15\,t_s}{sd''}$

When the reduction to mid-wire is made in this manner, the value of the reduction is of course omitted from the value of e.

NOTE.—Both Brünow and Chauvenet give, in their discussions of the subject of moon culminations, the amount of error introduced into the longitude of a place by the error of the transit, if corrections are not applied for it; but neither of them, nor as far as I know, any other authority has recommended, or given, a detailed plan for neglecting these corrections during the computations, and uniting them in a single correction to be applied to the longitude deduced by the simple processes which are available when they are thus used.

The process followed in the case in which the British Ephemeris is used is taken, almost without change, from that given in Lee's Tables, as contributed by Prof. W. H. C. Bartlett; the changes in it are simply such as are necessary to adapt it to the method given above.

The hourly ephemeris of the moon as given in the British Ephemeris may be used in the same way precisely as that given for the American Ephemeris, if it should be preferred.

I have purposely selected, for illustration, an example in which all the instrumental constants are large, and in which the moon was not observed on the first wire.

The value of p, the parallax in hour angle is only $^s0.14$ for a transit error of $^s10.04$, showing that for small inaccuracies in adjustment of the transit, this term may be omitted without appreciably affecting the result.

EXAMPLE.

The moon's first limb and seven stars were observed at Willet's Point, N. Y., on September 24th, 1874. The notes showing for the moon as follows:

	h.	m.	s
1st Wire lost.			
2nd "	23	29	32
3rd "		29	55.5
4th "		30	23.0
5th "		30	50.0
Sum		120	40.5
Mean	23	30	10.12
Reduction to mid-wire			—14.64
Level			—.03
Collimation			—4.42
Deviation			+9.05
Chronometer error			+2 10.83
AR	23	32	10.91

From the seven stars the chronometer was found to be slow 2m. 10.83s.

The reductions for the moon, whose declination was —6° 07′, were deduced from these stars, the algebraic sum of all these except the chronometer correction being —10.04.

Moon Culmination September 24th, 1874.

British Ephemeris.

h. m. s.

Obs. AR ☽. I. L. Willet's Point = 23 32 10.91

Eph. AR ☽. I. L. Greenwich = a′ = 23 20 48.89

h. m. s. m = 682.02s = 11 22.02

l′ = 4 55 06.0

h. m. s.

September 23, Gr. U. C. = 22 24 42.44

+28 12.77

" " " L. C. = 22 52 55.21 —19.09

+27 53.68 +7.05

" 24 " U. C. = 23 20 48.89 —12.04 +1.29

+27 41.64 +8.34 —1.61

" " " L. C. = 23 48 30.53 — 3.70 —0.32

+27 37.94 +8.02

" 25 " U. C. = 24 16 08.47 +4.32

+27 42.26

" " " L. C. = 24 43 51.73

$$d_1 = 27\ 41.64, d_2 = \frac{-12.04 - 3.70}{2} = -7.87, d_3 = +8.34, d_4 = \frac{+1.29 - 0.32}{2} = +0.49, d_5 - 1.61$$

	m.	s.	s.
$A = d_1 - \frac{1}{2}d_2 + \frac{1}{12}d_3 + \frac{1}{24}d_4$	= 27	46.28	= +1666.28
$B = \frac{1}{2}d_2 - \frac{1}{4}d_3 - \frac{1}{24}d_4$	= −6.00		= − 6.00
$C = \frac{1}{6}d_3 - \frac{1}{12}d_4$	=		+ 1.35
$D = \frac{1}{24}d_4$	=		+ 0.02

$$t = \frac{4\text{ h. }55\text{ m. }06\text{ s.}}{12\text{ h.}} = \frac{295.1}{720.} \quad \ldots\ldots \log = 9.6126367$$

* * * * * * * * *

A log = 3.2217344	B log = −0.7781513
t " = 9.6126367	t^2 " = 9.2252734
At " = 2.8343711...No. = +682.922	Bt^2 " = −0.0034217...No. = −1.008
C log = 0.1303338	D log = 9.3010300
t^3 " = 8.8379101	t^4 " = 8.4505468
Ct^3 " = 8.9682439...No. = +0.093	Dt^4 " = 7.7515768...No. = +0.006

$m' = 683.021 - 1.008 = 682.01$ s. $\qquad m - m' = 00.01$ s.

A = 1666.28	B log = 0.7781513	C log = 0.1303338
2Bt = −4.92	t " = 9.6126367	t^2 " = 9.2252734
$3Ct^2$ = 0.68	2 " = 0.3010300	3 " = 0.4771213
V = 1662.04	−4.918 − 0.6918180	0.6803 .9.8327285

H log = 4.6354837	log 10.04	1.0017
$m - m''$ " = 8.0000000	sin 60′ 50″	8.2478
a.c. of V " = 6.7793586	cos 40° 47′ 17″	9.8792
e " = 9.4148423 = No.0.2599	sec 6° 07′ 42″	0.0025
	p = 0.1353	9.1312

$$p = 10.04^s . \sin 60' 50'' . \cos 40° 47' 17'' . \sec(-6° 07' 42'') = 0.1353^s$$

$$L = 4\ 55\ 06 + 0.26 - (10.04 - 0.14) = 4\ 54\ 56.36$$

AMERICAN EPHEMERIS.

	d.	h.	m.	s.
Observed siderial time of transit 1st L.	24	23	32	10.91
Ephemeris siderial time of s.d. crossing meridian			1	09.37
Observed siderial time of transit of moon's center	24	23	33	20.28
Assumed longitude l′			4	55 06.00
Gr. siderial time of transit at Willet's Point	25	04	28	26.28
Gr. siderial time of mean noon	25	12	16	32.47
Siderial interval	—	7	48	06.19
Retardation			1	16.69
Mean solar interval	—	7	46	49.50
Gr. mean time of transit at Willet's Point	24	16	13	10.50

	d.	h.	m.	s.			h.	m.	s.
Moon's AR at	24	16	00	00.00	by	Ephemeris	= 23	32	50.33
" " "	24	16	13	10.50	"	Observation	= 23	33	20.28
Difference			13	10.50 = 13.175 m. = t					29.95

Interpolate the increase for 13 m. 10.50 s = t neglecting 2nd differences,

$$td_{,} = 13.175 \times 2.2288 = 29.363$$

Interpolated difference = 29.36, observed = 29.95, difference = 0.59

Difference in AR in one second of time by Eph. = 0.037, hence e = 15.946

and L = 4 55 06 + 15.946 − (10.04 − 0.14) = 4 55 12.05

The difference in the values of the longitude of Willet's Point found by the use of the two ephemerides results almost entirely from the moon tables employed in their construction. The AR of the moon as given in the British Ephemeris for September 24th, at 16 hours, differs from that given in the American for same epoch by 0.61 s, which corresponds to a difference in the resulting longitude of 16.426 s: this differs from the difference of longitude as determined by 0.74 s, corresponding to a discrepancy of AR of 0.02; which amount might easily be introduced into the calculations by a small error in the assumed time of the semidiameter passing the meridian, by omitting the higher terms of the interpolating formulas, or by neglecting fractions in the different quantities used.

THEORY

OF

SIMULTANEOUS IGNITIONS.

READ BEFORE THE ESSAYONS CLUB OF THE CORPS OF ENGINEERS,

APRIL 3, 1876;

BY

BVT. BRIG. GEN. HENRY L. ABBOT,
MAJOR OF ENGINEERS.

NO. XXXIX. PRINTED PAPERS.

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SIMULTANEOUS IGNITION OF MINES.

A paper read* before the "ESSAYONS CLUB" of the Corps of Engineers, on April 3rd, 1876, by Bvt. Brig. Gen. Henry L. Abbot, Major Corps of Engineers.

To produce the maximum effect in removing obstructions, and in other similar work, both civil and military, pertaining to the duties of the Corps of Engineers, it is often desirable to cause the simultaneous explosion of many mines; or, sometimes, the simultaneous ignition of many fuzes distributed throughout the charge of one large mine. In the present state of science, this will always be effected by electricity; and the form usually preferred will be the voltaic or magneto-electric current acting upon numerous low tension fuzes. Such fuzes may be united either in series i.e. fuze connected to fuze in a single circuit (fig. 1), or in derived circuits i.e. each fuze connected to both of the main lead wires (fig. 2), or in some combination of these two methods (fig. 3); and the maximum number which it is possible to explode simultaneously by a given battery or magneto-electric machine, will vary according to the grouping adopted.

General Theory.

I am not aware that any mathematical investigation has been made to determine the rules which should govern the Engineer in arranging such groups; and as the matter is not without practical importance, in ordinary as well as in large blasts, I have analyzed the problem with the following results. Let:

E = the available electro-motive force in volts.

R, = the corresponding internal resistance in ohms.

C = the current in webers needful to fire one of the groups connected in series—all such groups being supposed equal in electrical resistance.

L = the resistance in ohms of the main lead wires connecting the source of electricity with the groups.

F = the resistance in ohms of each fuze at the instant of explosion. This includes the increased resistance due to the heating of the fine wire bridge, and also the resistance of the needful local connections.

* Also read before the National Academy of Sciences, on April 18th, 1876.

N = the total number of fuzes which can be exploded simultaneously.

n = the number of fuzes connected in series to form a single group.

$\frac{N}{n}$ = the number of such groups connected in derived circuit.

From well known electrical laws, the following general equation for the blast can be stated—each number representing the total strength of current necessary to cause the explosion.

$$(1) \qquad \frac{N}{n} C = \frac{E}{R_{,} + L + \frac{n F}{\frac{N}{n}}}$$

Solving this equation with respect to N, and finding its first differential coefficient regarded as a function of n, we have :

$$\frac{d N}{d n} = \frac{E - 2 F C n}{C (R_{,} + L)}$$

Placing the second member equal to zero, and combining the resulting equation with Eq. (1) we have for the conditions of the desired maximum :

$$(2) \qquad N = \frac{E^2}{4 F C^2 (R_{,} + L)}$$

$$(3) \qquad n = \frac{E}{2 F C}$$

$$(4) \qquad \frac{N}{n} = \frac{E}{2 C (R_{,} + L)}$$

As a check upon the computation, the following value of C, derived from Eq. (1), should be nearly the same as the assumed value. They probably will not be identical—since fuzes and groups cannot be subdivided, and fractions in n or $\frac{N}{n}$ must, therefore, be ignored.

$$(5) \qquad C = \frac{E}{\frac{N}{n} (R_{,} + L) + n F}$$

It is evident that these equations furnish a mathematical basis for a thorough practical discussion of the subject, for not only do they reveal the maximum number of simultaneous explosions which can be obtained with any particular generator of electricity, type of fuze, and kind of lead wire, but they also indicate the relative importance of the different constants, and hence point out the principles which should control the selec-

tion of apparatus and materials for any difficult blast. Of these constants, the numerical values of E and $R_{,}$ vary with the nature of the generator of electricity; those of F and C depend upon the construction of the fuze; while L is fixed by the conductivity and cross section of the metal selected for the main lead wires.

The first glance at Eq. (2) shows that N increases directly with E^2 and inversely with C^2 F $R_{,}$ and L—hence, as the squares of E and $\frac{1}{C}$ enter the formula, particular attention must be given to making these quantities as large as possible.

Again, a little consideration will reveal the extreme importance of making L disappear in these equations. This can and always should be done, either by using rods so large as to offer no sensible resistance to the current, or by causing the several groups to diverge at the poles of the battery, and increasing F accordingly. In this case, Eq. (4) may be put under the form:

$$\frac{N}{n} = \frac{1}{2\,C} \times \frac{E}{R_{,}}$$

Now, since E and $R_{,}$ are both directly proportional to the number of elements coupled in series, this equation reveals the curious fact that when all the cells of a voltaic battery are so coupled, the proper grouping of the fuzes is quite independent of the number of cells; i.e. the proper number of groups to be used in derived circuit is constant, no matter how many cells are coupled in series. Hence, so far as the number of groups is concerned, the relative merit of different types of battery is in the direct ratio of the numerical values of the quotient $\frac{E}{R_{,}}$ for a single element.

But Eq. (3) shows that, with any type of battery, the number of fuzes which can properly be placed in each group is directly proportional to the number of cells coupled in series; also, that the relative merit of different elements in this respect is directly proportional to their electro-motive force per cell.

This analysis makes it clear that, in choosing a battery for a large blast, it is only necessary to consider the numerical value of the ratio $\frac{E^2}{R_{,}}$ for a single cell, the cost per cell (K), and the relative convenience (economy) of manipulation (M); that is, the figure of merit for any type of battery is proportional to $\frac{E^2\,M}{R_{,}\,K}$.

For example, suppose one type of battery (A) to have an electro-motive force of 2.0 volts, an internal resistance of 0.2 ohms, a cost of $10.00 per cell, and a relative econ-

omy of manipulation denoted by 5; and a second type (B) to have for these quantities, respectively, the values 1.0 volts, 0.5 ohms, $1.00 and 3. Then, for relative merit:

$$\text{Type (A)} \cdots\cdots \frac{2^2 \times 5}{0.2 \times 10.00} = 10.$$

$$\text{Type (B)} \cdots\cdots \frac{1^2 \times 3}{0.5 \times 1.00} = 6.$$

That is, the more costly type would really be the more economical battery in the ratio of 10 to 6.

Another point likely to suggest itself, is how any given number of cells ought to be divided in separate circuits, and coupled in each circuit, to secure the best result. Although the statement may at first seem to be a little paradoxical, the matter is one simply of convenience. This is evident from a study of Eq. (2); for when L is eliminated, as we have seen should always be done in practice, if we denote by x the number of cells coupled in series and by y the number coupled in derived circuit, e and $r_{,}$ referring to a single cell:

$$N = \frac{1}{4\,C^2\,F} \times \frac{x^2\,e^2}{\frac{x\,r_{,}}{y}} = \frac{1}{4\,C^2\,F} \times \frac{e^2}{r_{,}} \times x\,y$$

Hence no change in N can be caused by any variation in the arrangement of the cells, provided only that, as required by Eq. (3), $\frac{x\,e}{2\,n\,F}$ be never made less than C. Indeed, a little reflection will show that this must be the case, since by the theory of the method the fuzes are always so grouped as to develop the maximum energy attainable from the elements; and, of course, no mere change of arrangement can generate or destroy energy. In practice, then, the number of cells to be coupled in series would be determined by the number of fuzes which could most conveniently be united in single groups; while the number of cells to be coupled for quantity would depend upon the desired number of groups in each circuit. From these conditions, in the case of very large blasts, the dividing of the battery into separate circuits to be closed simultaneously, naturally results. The general formulæ for these computations are the following, derived from Eq. (3) and Eq. (4):

$$x = \frac{2\,F\,C}{e}\,n$$

$$y = \frac{\frac{N}{n}\,2\,C\,x\,r_{,}}{x\,e - \frac{N}{n}\,2\,C\,L}$$

As has already been repeatedly stated, the quantity L should be made to disappear by a judicious selection and arrangement of the lead wires and connections. If this be neglected, great loss of power will be unavoidable, as is apparent from the latter of these equations. Indeed, the chief reason for recognizing this quantity in framing Eq. (1), was to exhibit clearly the importance of making it zero.

In choosing the fuze, the quantities F and C are to be considered. The conditions to be fulfilled by the former are simple, since it is only necessary that it be as small as possible consistent with securing the minimum value for C; and this, aside from the choice of suitable local lead wires, is a matter only to be learned by judicious experiment. The quantity C calls for more careful study.

In the method I have devised for use at the School of Submarine Mining at Willet's Point, in determining the number of webers needful to explode a single low tension fuze of any particular type, the fuze and a standard Helmholtz-Gaugain galvanometer of low resistance are placed in the unknown side of a Kirchoff-Wheatstone bridge. The known side is a standard ohm. The battery consists of three small Grove cells in good condition, and contact is made by the sliding piece upon the platinum-iridium wire which forms the two variable sides of the bridge. For balancing, a Service Bradley galvanometer is employed, use being made of the coil having about an ohm resistance. In the main battery circuit is included a Wheatstone rheostat having a total resistance of about 40 ohms, by which the current can easily be regulated. Three operators are needful—one to gradually increase the current, by unwinding the wire from the wooden to the brass cylinder of the Wheatstone rheostat, until the fuze explodes; one to keep the bridge balanced by moving the sliding contact piece on the wire, as the resistance of the fuze increases under the heating effect of the current; and one to read the Helmholtz-Gaugain galvanometer, which, since the weber coefficient has been accurately determined, makes known the current traversing the fuze at any instant.

By this method, the resistance of the fuze when cold, and at any subsequent temperature, may be noted exactly; while the corresponding current is accurately measured up to the instant of explosion.

In this manner the constants of many different types of fuzes have been experimentally determined.

The following table exhibits the data for four of them, which will be designated as A, B, C and D. Type A consists of $\frac{3}{16}$ inches of platinum wire 0.0025 inches in diameter; type B of $\frac{3}{16}$ inches of platinum silver wire 0.0015 inches in diameter; type C of $\frac{3}{16}$ inches of gold iron wire 0.0020 inches in diameter; and type D of $\frac{4}{16}$ inches of platinum silver wire 0.0015 inches in diameter—all charged with a priming of fulminating mercury.

CONSTANTS OF SINGLE FUZES.

Types.	Resistance in ohms.			Current in webers to effect explosion.
	Cold.	At explosion.	Diff.	
A.	0.72	0.82	0.10	0.45
B.	1.49	1.57	0.08	0.33
C.	1.87	1.96	0.09	0.34
D.	1.90	2.01	0.11	0.28

The method of measurement just described, gives accurately the current required to effect the explosion of a single fuze—but it is needful to observe that *time* enters as an element. For a single fuze this is not important, since the interval is exceedingly small; but when fuzes connected in series are employed, it cannot be ignored. Experience shows that in this case, unless an excess of current be used, the most sensitive fuze explodes first, and by breaking the circuit saves its neighbors.

Without going too much into detail it is sufficient to state, what both theory and experiment establish, that when fuzes are united in series the current which is strong enough to ensure the explosion of two will explode any greater number, if they be carefully tested to secure uniformity; also, that unless a current which deflagrates the fine wire be used, some fuzes are almost sure to fail. For type A this current is 1.03 webers, or more than double that required to explode a single fuze. But even this strength of current is not sufficient to ensure explosion in series, as the following table derived from many hundred measurements demonstrates:

TRIALS WITH FUZES COUPLED IN SERIES.

Type A.		Type D.	
Currents varying from.	Percent fail.	Currents varying from.	Percent fail.
webers.		webers.	
1.0 to 1.2	33	0.40 to 0.45	67
1.2 " 1.3	8	0.45 " 0.50	44
1.3 " 1.4	3	0.50 " 0.55	33
1.4 " 1.5	1	0.55 " 0.60	17
1.5 & more	0	0.60 " 0.65	8
		0.67 & more	0

Hence, it would not be absolutely safe to assume C to be less than 1.5 webers for type A, nor less than 0.67 for type D, in the general formulæ given above.

There is, however, one particular case which must not be overlooked —viz: where a ~~single~~ derived circuit is arbitrarily chosen, or in other words when n is assumed to be unity. Evidently with this system of connections the most sensitive fuze will explode as soon as the minimum needful current traverses it; and by so doing it will increase the current flowing through the others, some of which in their turn may now detonate. Hence, if the minimum current required to fire a single fuze be passed through the group, an explosion will probably occur in a rattling volley like the fire of a skirmish line. To this case the general formulæ are inapplicable, since from the manner in which they have been deduced no arbitrary value can be assigned to n; use must, therefore, be made of Eq. (1), from which, when $n = 1$, we find:

$$(6) \qquad N = \frac{E - F C}{C (R_{,} + L)}$$

In this equation the value of C is independent of time—or, in other words, for type A it is 0.45 webers, and for type D, 0.28 webers.

In like manner, if the fuzes be arbitrarily united in a single series, the general formulæ are inapplicable; but the number which can be exploded will be found from Eq. (1) to be:

$$(7) \qquad n = \frac{E - C (R_{,} + L)}{C F}$$

This second case is not likely to mislead —because C must have the value pertaining to two or more fuzes, i.e. for type A it must be 1.5 webers and for type D, 0.67 webers, and, if the grouping in single series be the best, the fact will be indicated by $\frac{N}{n}$ becoming unity in the general formulæ. For the first case, however, since a different value of C is used, it is always well to compare the numerical value of N in Eq. (6) with that in Eq. (2) before deciding upon the manner of grouping to be adopted. It must not be forgotten, however, that the explosions will probably be much more *simultaneous* if the larger current be used.

Practical Verifications of the Theory.

As a practical test of the foregoing theory, a trial was made with a blasting battery of nine cells, consisting of zinc and coke plates immersed in a solution of bichromate of potash containing the usual percentage of sulphuric acid. The opposed surfaces were $4\frac{1}{2} \times 4\frac{1}{2}$ inches, separated $\frac{1}{2}$ an inch—and fuzes of the type A were used. The constants of the battery, freshly set up, had been found by very careful measurement to be as fol-

lows for electro-motive force 1.95 volts per cell, and for internal resistance 0.15 ohms per cell; the main lead wires had a resistance of 0.12 ohms; F was 1.0 ohms; and C was assumed to 1.33 webers. Under these circumstances, Eq. (2), (3) and (4) indicated that the best grouping would be five series of six fuzes each—giving thirty explosions, with a current through each fuze of 1.32 webers. Upon trial the whole exploded so nearly together that only one sound could be detected by the ear.

To compare this result with a simple grouping in series, use was made of Eq. (7); which showed that 12 fuzes could be thus exploded. As those selected fell a little below the average resistance, 13 were tried; and they all instantly detonated, the current through each fuze being 1.30 webers. On trying 17, which allowed a current of precisely 1 weber to pass, 7 exploded and 10 failed.

Lastly, Eq. (6) indicated that in simple derived circuit 26 fuzes could be fired, with a current through each fuze of 0.45 webers. Trial showed this to be the case, but the sound was a little lengthened. On repeating the experiment with 35 in circuit, none exploded; on removing a single fuze, 3 others detonated; on a third closing of the circuit, the rest went in a prolonged volley—showing that too much had still been demanded of the battery.

In like manner, six cells of the same battery were tried with type D; and Eq. (2) (3) and (4) showed that the best grouping would be nine series of four fuzes each—giving a current through each of the 36 fuzes of 0.67 webers. On trial, they all detonated instantly, with no lengthening of the sound. If the whole battery of nine cells had been used, the grouping would have been nine series of seven fuzes each—giving 63 fuzes, through each of which 0.64 webers would have passed.

Upon comparing these results, it is evident that the new formulæ correctly indicated the best grouping.

Application of the Theory to Large Blasts.

It only remains to illustrate, by a practical example, the uses of the foregoing theory where a great number of mines are to be exploded; and, to give variety to the discussion, the capacity of a magneto electric machine made by the Laflin and Rand Powder Company will be computed. This machine is a modified Wild, the permanent magnets being replaced by an electro-magnet actuated by a small Siemens' armature which supplies the current for creating the magnetic fields in which it and the working Siemens' armature revolve. The machine weighs about 900 lbs.; requires about 4 horse-power to give 1500 revolutions per minute on short circuit; and occupies a space of 34 inches by 14 inches by 42 inches high. I lately made a very careful measurement of the power of this

machine, with delicate instruments and methods; and, for a range covering the usual working speed, found its equation to be the following, in which:

Q = the current in webers.
T = the number of revolutions of the armature per minute.
R = the external or working resistance in ohms.

$$(8) \qquad Q = \frac{0.02395\ T}{0.043 + R}$$

For the proposed computation, I shall assume T = 1500, giving for E 35.92 volts. R, is 0.043 ohms. Let it first be supposed that fuzes of the type A are used; requiring for sure ignition, C to be equal to 1.5 webers, and F, including the connecting wires, to be 1.0 ohm. Making use of ordinary lead wires for carrying the current from the machine to the groups, I will assume them to be of copper No. 13 B. W. G., each 500 feet long—giving for L say 2.0 ohms. Then by equations (2) (3) (4) and (5):

$$N = 70.2, \text{ or say } 72$$
$$n = 11.97, \text{ or say } 12$$
$$\frac{n}{N} = 5.86, \text{ or say } 6$$
$$C = 1.48 \text{ webers.}$$

This result being far from satisfactory, let equation (2) be inspected to determine the cause; evidently, unless the machine or the rate of revolutions of the armature or the fuzes be changed, the quantity L offers the only field for improvement. Accordingly let the 1000 feet of lead wire of No. 13 B. W. G., be replaced by copper rods an inch in diameter, having a resistance of say 0.01 ohms. We then shall find:

$$N = 2704., \text{ or say } 2712$$
$$n = 11.97, \text{ or say } 12$$
$$\frac{n}{N} = 225.9, \text{ or say } 226$$
$$C = 1.498 \text{ webers.}$$

Hence, by simply subtracting 1.99 ohms from the resistance of the main lead wires, the number of simultaneous explosions has been increased nearly thirty-eight times, and yet a stronger current is sent through every fuze.

For the last arrangement, in which alone regard was paid to scientific principles, we find in equation (1):

$$R' = 0.043$$
$$L + \frac{n\,F}{\frac{N}{n}} = 0.063$$

In other words, the well known condition that, to develop the maximum power of any battery, the internal must equal the external resistance is approximately fulfilled. If L could conveniently be made zero, the accordance would be exact; and, provided F were not increased thereby, 3348 of these fuzes could be exploded together.

To illustrate the importance of carefully selecting the fuze, the last computation will be repeated for type D. In this case, with L = 0.01 ohms as before, we find:

$$N = 6776, \text{ or say } 6578$$

$$n = 13.4, \text{ or say } 13$$

$$\frac{N}{n} = 505.7, \text{ or say } 506$$

$$C = 0.68 \text{ webers.}$$

In fine, then, this portable machine, requiring only about four horse-power, will supply an ample magneto-electric current to meet nearly any demand likely to arise in submarine blasting upon the most extensive scale known upon modern works of internal improvement. From the principle of its construction internal resistance is nearly eliminated, rendering it possible, by proper grouping and the selection of a suitable fuze, to obtain the astonishing results indicated above. But even these figures may readily be exceeded, as is apparent from the following considerations.

Since N increases with the square of the electro motive force and diminishes with the first power of the internal resistance, this particular instrument is susceptible of improvement. The armature is wrapped with 190 feet of a square copper rod, about 0.2 inches on the edge, weighing about 30 lbs., and insulated with a silk ribbon. Since the electro motive force is a function of the number of convolutions of the armature, they might advantageously be increased; and the foregoing formulæ furnish indications as to the extent to which this may best be done for any particular blast.

Possibly more care in adjusting the commutator might also be of service; for, with Siemens' armature, the pulsating currents are not so perfectly thrown in one direction as is generally supposed. This may readily be shown to the eye in any machine by an electrometer, or by a Thomson galvanometer and condenser, using Law's method. In this manner, nil and even reversed currents may often be noted. It is true that they are of too short duration to cause vibration in the needle of an ordinary galvanometer included in the direct circuit; but their influence upon the instantaneous heating of a fine wire may perhaps be considerable, since they evidently must reduce the effective electro-motive force. The Gramme type of machine perfectly obviates this difficulty.

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FIG.1 9 FUZES IN SERIES.

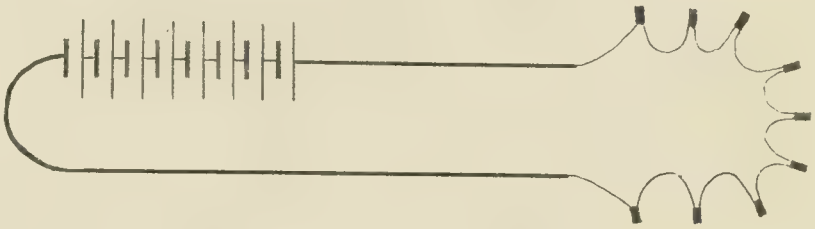


FIG.2. 9 FUZES IN DERIVED CIRCUIT.

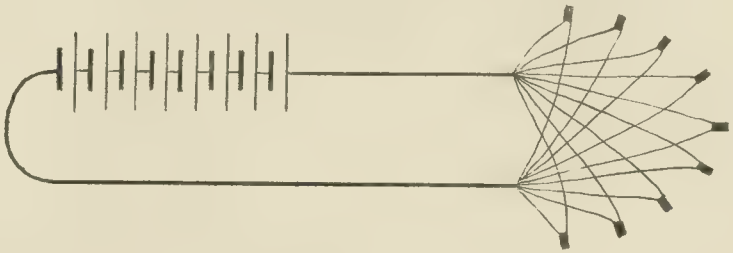
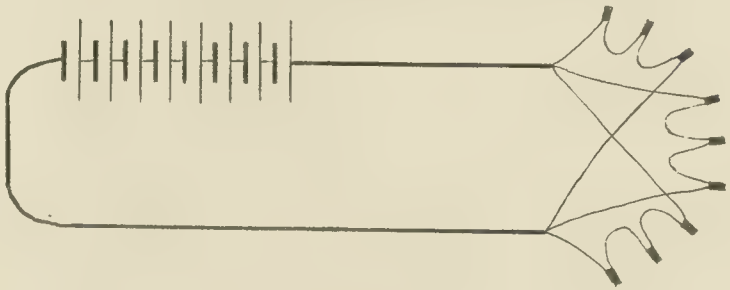


FIG.3. 9 FUZES IN COMBINED CIRCUIT.



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Essayons Club—Professional Memorandum, No. 1.

Communicated by 1st Lieut. E. W. Bass, Corps of Engineers, January 24, 1876.

PRELIMINARY METHOD FOR REDUCING TRANSIT OBSERVATIONS.

The following method for the preliminary reduction of transit observations, I obtained from Professor C. H. F. Peters.

It avoids the disconnected operations of determining the azimuth, and collimation corrections for the instrument separately; and the results have a degree of accuracy due to a combination of all the stars observed.

If possible, an equal number of stars with circle each way should be observed, including four stars near the pole—one above and one below in each position of the circle. Each observation is then reduced to the middle wire; corrected for error in level; and the result diminished by the AR of the star. This will give the numerical value of the sum of the first three terms in the formula for the clock error

$$E = \left[T + \frac{\text{Cos. } (L-D)}{\text{Cos. } D}\, b - AR\right] + \frac{\text{Sin. } (L-D)}{\text{Cos. } D}\, a + \frac{1}{\text{Cos. } D}\, c$$

Then for each star observed, an equation can be formed, containing three unknown quantities "E," "a" and "c," as in the following example.

EXAMPLE.

Circle East.	
ζ Eridani	$E = 35.30 - 0.592\,a + 1.013\,c$
ε Eridani	$E = 35.34 - 0.584\,a + 1.015\,c$
10 Tauri	$E = 35.23 - 0.708\,a + 1.000\,c$
B.A.C. 1150	$E = 35.20 - 0.260\,a + 1.184\,c$
Circle West.	
ν Tauri	$E = 36.00 - 0.777\,a - 1.005\,c$
ν Eridani	$E = 36.27 - 0.663\,a - 1.002\,c$
η^4 Orionis	$E = 36.02 - 0.774\,a - 1.004\,c$
η^5 Orionis	$E = 36.03 - 0.735\,a - 1.000\,c$
Mean of above	$E = 35.675 - 0.636\,a + 0.025\,c$(1)

The similar equation for stars near the pole are

C. E. (No. 12) (S.P.) $E = 37.330 - 7.479\,a - 9.633\,c$

C. E. (No. 13) $E = 35.270 + 1.862\,a + 3.771\,c$

C. W. (No. 14) (S.P.) $E = 24.020 - 11.123\,a + 14.772\,c$

C. W. (No. 16) $E = 42.150 + 5.189\,a - 8.405\,c$

Subtracting each term of equation (1) from the corresponding term in each of these four equations we have.

$$O = + 1.655 - 6.843\,a - 9.658\,c \quad \ldots\ (2)$$
$$O = - 0.405 + 2.498\,a + 3.746\,c \quad \ldots\ (3)$$
$$O = - 11.655 - 10.487\,a + 14.747\,c \quad \ldots\ (4)$$
$$O = + 6.475 + 5.825\,a - 8.430\,c \quad \ldots\ (5)$$

These equations are now combined so as to give two, one of which shall have a large coefficient for a and a small one for c; while the other will have the large coefficient for c, and small one for a.

In the above example, by changing the signs in equations (3) and (5), then adding we obtain

$$O = - 16.07 - 25.653\,a + 9.773\,c \quad \ldots\ (6)$$

the same with equations (3) and (4),

and adding we have

$$O = + 20.19 + 6.971\,a - 36.581\,c \quad \ldots\ (7)$$
$$a = - 0.626 + 0.381\,c \quad \ldots\ (6)$$
$$c = + 0.552 + 0.191\,a \quad \ldots\ (7)$$

From inspection, assuming $a = -.5$, and substituting in Eq. (7), an approximate value for c is obtained, which substituted in Eq. (6) will give a nearer approximation to the value of a. So on for two or three approximations, and there will result

$$\left.\begin{aligned} a &= - 0.451 \\ c &= + 0.466 \end{aligned}\right\} \text{ Substitute in Eq. (1).}$$
$$E = + 35.970$$

A check upon the work, will be to substitute these values in the equations for the stars near the pole, and see whether they are nearly satisfied.

When the reductions are to be made immediately after the observations—tables containing the values of the coefficients of a, b, and c, should be prepared before hand for all the stars which are to be observed. This method will then require about half an hour to determine the clock error and instrumental corrections, with a degree of accuracy only excelled by combining the observations by the method of least squares.

SHOCK

OF THE

EXPLOSION AT HALLET'S POINT.

READ BEFORE THE ESSAYONS CLUB OF THE CORPS OF ENGINEERS,

NOVEMBER 14, 1876;

BY

BVT. BRIG. GEN. HENRY L. ABBOT,
MAJOR OF ENGINEERS.

NO. XL. PRINTED PAPERS.

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ERRATUM.

PAGE 157—line 10 from top. Cancel the sentence, and substitute the following: –

A discussion of these observations indicated that, when the vis viva of the shot at impact varies proportionally with $D^{1\cdot 2}$, similar tremors affect the seismometer. Hence:

SHOCK OF THE EXPLOSION AT HALLET'S POINT.

A paper read* before the "ESSAYONS CLUB" of the Corps of Engineers, on November 14th, 1876, by Bvt. Brig. Gen. Henry L. Abbot, Major of Engineers.

In June 1876, Prof. J. W. Mallet of the University of Va. addressed a communication to the Secretary of the Smithsonian Institution, suggesting that advantage should be taken of the great blast at Hallet's Point to revise the experimental results obtained by his father and himself, many years ago, respecting the rate of transmission through the earth's crust of an artificially produced impulse analogous to an earthquake shock. Prof. Henry referred this paper to the Chief of Engineers, who forwarded it for report to General Newton, in charge of the works at Hallet's Point. That officer stated that he would cordially co-operate in the proposed observations, but that from want of time he could not give them personal attention. General Humphreys then issued instructions placing the matter in my charge, and authorizing the employment of the officers and enlisted men of the Battalion of Engineers, and the use of such instruments, insulated wire, etc., as might be available at the School of Submarine Mining at Willet's Point.

My attention had already been drawn to the subject, in a general way, by the vibrations produced by ordinary torpedo explosions, which are often noticeable at distances exceeding a mile. Prof. Mallet kindly loaned several volumes containing reports of his father to the Royal Society upon Earthquakes, and verbally explained the seismometer used in the investigations mentioned in his communication to Prof. Henry. The same general method has been carried out in the measurements upon the Hallet's Point explosion, with such improvements as the progress of science has suggested.

PRELIMINARY PREPARATIONS.

No funds were available for the purchase of instruments; but the Engineer Depot contains many worn out and condemned articles, and from them, with the assistance of Capt. Livermore, the seismometers described below were improvised. The needful rec-

* Also read before the National Academy of Sciences, on October 18th, 1876.

isters, batteries, relays, keys, chronometers, etc., and the means of accurately adjusting and rating them were on hand, and require no special mention.

Seismometers. If an ordinary artificial horizon of mercury be placed on solid ground remote from the vicinity of trees, passing vehicles or other causes of accidental vibrations, and the reflection of some convenient object from the surface of the mercury be closely watched, any tremor in the latter is instantly detected. By using a microscope the delicacy of the instrument is increased; and by varying the magnifying power, a wide range of sensitiveness is secured. Such a variation is desirable when stations at different distances are to be occupied, because an unnecessary sensitiveness increases the danger of losing the observation from an accidental tremor.

Two kinds of these seismometers were employed. One, which will be designated as type A, was made by attaching a black silk thread to one of the glasses of the artificial horizon cover, and observing its reflection by a sextant telescope mounted on a small tripod. The magnifying power employed in this case was about six diameters.

For more distant stations, the telescope of a railroad transit, having a magnifying power of about twelve diameters, was used—and, to avoid placing it at an inconvenient distance from the mercury, the reflection of the cross hairs of another similar telescope with the eye piece removed, was observed. This type will be designated as B. A man walking at a distance of 10 feet, or a horse trotting at a distance of 300 feet, shakes the ground sufficiently to be readily detected with this arrangement.

Empirical Formulæ and Constants. To select stations for the observers judiciously, in the absence of any data upon an explosion of so exceptional a character, a rough investigation of the laws governing the transmission of such impulses was undertaken. Denoting by S the tremor causing the minimum disturbance of the mercury, which could be detected by the type of instrument to be employed; by D, the distance separating the instrument from the initial disturbance causing S; and by C, the weight of the explosive, it is plain that we have the equation:

$$(1) \qquad S = \frac{f(C)}{f(D)}$$

Experiments were first directed to determining the function of D entering the second member. To do this, it was necessary to find the values of D corresponding to a series of artificial disturbances that could be precisely regulated, and that were of the same nature as that resulting from the explosion—which since dynamite was to be used might safely be assimilated to a blow. No better plan suggested itself than to make use of the fall of a heavy body through small known heights, in which case the shock might be assumed to be directly proportional to the work performed, i. e. to the height.

Accordingly a cart was so arranged that a 13-inch shot, weighing 283 lbs., could be dropped precisely 2 feet or 4 feet as desired, giving a blow, respectively, of 566 and 1132 foot lbs. Instruments of type A and B were placed side by side upon a solid road, and the cart was moved further and further until the tremors caused by dropping the shot through these heights could only be just perceived, thus giving for each instrument two values of D corresponding to known shocks. A path running near sustaining walls, and over a drain 20 feet below the surface, gave another set of numerical values differing slightly from the first, but following the same law. Other values were found by dropping stones of known weight through known heights.

A discussion of these observations indicated that the vis viva of the shot at impact is proportional to $D^{1.2}$. Hence:

$$(2) \qquad S = \frac{f(C)}{D^{1.2}}$$

The form of the function of C could best be determined by firing small charges of dynamite, bedded in the ground, at different distances, and noting when they gave a tremor just perceptible. This was done with the following results.

Type A just detects the tremor due to 2 oz. at 660 feet, failing for 1 oz.; and plainly detects the tremor due to 8 oz. at 1480 feet, failing with a much less quantity.

Type B plainly detects the tremor due to 2 oz. at 1480 feet, failing for 1 oz. A cartridge of 8 oz. gives, at this distance, a continuous vibration lasting about 2 seconds; and 12 oz., one lasting for $3\frac{3}{4}$ seconds. At 660 feet, the shock of 1 oz. is very noticeable.

These figures, considering the rough nature of the data, point to the square root of C as the desired function, giving the law:

$$(3) \qquad S : \frac{\sqrt{C}}{D^{1.2}}$$

Hence, substituting the numerical values found for the two types of seismometer employed, the units being the mile and the pound, we have:

$$(4) \qquad \text{Type A} \quad D = \sqrt[1.2]{\frac{\sqrt{C}}{3.26}}$$

$$(5) \qquad \text{Type B} \quad D = \sqrt[1.2]{\frac{\sqrt{C}}{1.63}}$$

These empirical formulæ were roughly tested by the vibrations caused by the torpedoes exploded this summer, during the prosecution of the submarine mining trials now in progress at Willet's Point, namely:

1st. A charge of 200 lbs. of dynamite, submerged 30 feet under an iron target, was fired on August 18. By Eq. (5) it should give a noticeable tremor at a distance of 6 miles. Captain Livermore distinctly detected it with an instrument of the B type, at a station 5 miles away.

2nd. A charge of 100 lbs. of dynamite, submerged 12 feet, was fired on September 2. It should have been perceived, according to Eq. (4) and (5), at extreme ranges of 2.5 miles and 4.5 miles respectively. Observers at 2.3 miles and 4.1 miles failed to detect it; but the exact instant of the explosion was unknown to them, and the wind and other conditions were unfavorable to so delicate observations on that day.

In fine, then, I considered that a more judicious selection of stations for the great blast could be made by regarding the indications of these formulæ than by any other method.

SELECTION OF STATIONS.

As the charge at Hallet's Point was to be about 50 000 lbs. of dynamite, the formulæ indicated 33 miles and 59 miles, respectively, as the distances for the extreme stations for seismometers of types A and B.

It was needful, however, to bear in mind that the mine was made up of thousands of small charges; and that this distribution might probably reduce the tremor. This fact, together with the importance of securing distinct observations at the few stations it would be possible to occupy, led me to prefer to err on the safe side.

The geographical situation of Hallet's Point with respect to land and water, was also to be considered; since it was desirable to detect any difference due to the nature of the route traversed by the vibration.

The telegraph system in the vicinity was also a matter of primary importance. Upon Long Island this is under the control of the Western Union Telegraph Co., but the railroad Companies have the right to send train messages. Both corporations freely extended every facility in their power without charge; doing, indeed, more than I had asked to promote the success of the experiments. To the Western Union, particularly, acknowledgments are due; for not only was the assistance of the operators freely granted, but special line men, even, were sent out to ensure the good condition of the wires.

Finally, five stations were selected. Three, Fresh Pond Junction, Jamaica and Springfield Junction, were on a land route extending in a south-east direction across Long Island; and were in telegraphic communication with Astoria, near Hallet's Point. Willet's Point lay to the eastward, nearly in the direction of East river, and offered a good water route. Lastly, West Point, to the north, was distant 52 miles; i. e. was nearly at the extreme range indicated by the formula for the most sensitive seismometer.

Lieut. Bass, Corps of Engineers, stationed at that post, kindly volunteered to observe there with a very powerful telescope; but the storm compelled him to change his plan, and to use one of type A which, as predicted by the formula, failed to detect any vibration.

TIME DETERMINATIONS.

The plan employed by General Newton to explode the mine, was the following. The charges were divided into 23 groups, for each of which a separate voltaic battery was provided. The circuits of these batteries were each complete except at one point. Here breaks existed between a set of mercury cups on a table, and corresponding brass points on a drop above. This drop was held up by a cord suspended from a small can, containing a charge of dynamite and a fuze. When, at the appointed time, the latter was exploded by an auxiliary battery, the drop fell and simultaneously closing all the circuits fired the mine. General Newton kindly provided an extra mercury cup and point for my use, and thus gave me an opportunity of causing the explosion to automatically register itself at the three stations to which an electrical circuit could be carried.

All the wires on Long Island are worked by batteries in the Western Union Building in New York City. A multiple cable carries the circuit across East river, near Hunters Point, and one core is thence extended in a loop to Astoria to work that office. For my observations, the current was sent from New York to Astoria, and thence along a single wire to the three inland stations selected—viz.: Fresh Pond Junction distant about 5 miles, Jamaica distant about 9 miles, and Springfield Junction distant about 13 miles from the mine. The wire was put to earth beyond the instrument at the latter station.

At each of these three stations, the line wire (plate I) passed through the coils of a relay arranged to close a local circuit when the current passed. These local circuits each contained a battery and a Morse register. Independent circuits containing the same battery and register were arranged, at each of the stations, to be closed at will by a key in the hand of the observer at the seismometer, who took post at the best position in the vicinity for obtaining good results—care being taken to secure a solid support for the mercury, and the minimum danger of interruption from passing vehicles, etc.

At Astoria the main line circuit was worked like a local, by a special battery; that is, it was attached to the contact points of a relay, and remained open except when this relay was acted upon by an auxiliary battery. The latter battery (10 cells Leclanchè) was placed at the firing station, with one pole to earth. The other pole was connected to a line of insulated torpedo cable, laid on the ground for the purpose. The current, on leaving the battery, passed first through a break circuit plug in the hands of the observer; thence through the coils of a relay, working a local circuit for recording the exact instant

of the explosion; thence to the mercury cup at the mine, where was situated the break to be closed by the drop at the explosion; thence to the coils of the relay at the Astoria office; and thence to earth.

The break at the drop was thus the only one in this auxiliary circuit; and it was closed by the same motion, and at the identical time, when the firing batteries exploded the 3680 fuzes. The effect was instantly to work the two relays of the auxiliary circuit. The one at the firing station registered the time; the one at the Astoria office closed the main line, and thus sent a current from the New York battery through the relays at the three stations, making a mark on each of the register papers. As soon as the observer at the firing station perceived that the mine had exploded, he withdrew the break circuit plug; all the relay contact points on the main line opened; and the register papers were each ready to receive the marks caused by the key of the observer at the adjacent seismometer, as he noted the tremor of the mercury.

By this system, the explosion recorded itself at each of the three stations with only the error due to three armature times—which probably did not exceed two tenths of a second; and even this small error was balanced by the time spent by the observers in closing their keys. Great care was given to securing a regular movement of the paper on the registers; and elaborate measurements, made just before and after the explosion, show that this object was attained with a probable error not in any case exceeding two tenths of a second. The most exact accuracy is, therefore, claimed for these measurements.

The stations at Willet's Point and West Point, not being on telegraph circuits, required different arrangements. As no tremor was detected at the latter place, the details for it possess no interest. Those for Willet's Point, however, are important, because the rate of transmission noted is surprising. Two good sidereal chronometers were employed. One is permanently kept in the astronomical observatory there, and its rate is known. The other was carried very carefully by boat to and from Hallet's Point, where it was used in making the absolute time marks on the register paper at the firing station. Careful comparisons were made at 6 A. M. and 6 P. M. of the day of the explosion—and again at 10 A. M. of the following day. They showed a discrepancy in the rates of only 0.4 seconds in twelve hours, proving that the latter remained sensibly unchanged during the three hours intervening between the blast and the second comparison.

The observations at Willet's Point were made in the observatory with a sensitive seismometer and Morse register, the absolute time being directly referred to the standard chronometer. By this method, a very close measurement of the time required for the tremor to pass to Willet's Point was secured, the error being probably a small fraction of a second.

DETAILS OF THE OBSERVATIONS.

The mine was exploded on September 24, 1876, at precisely 2 h. 50 m. 12.6 s. of New York mean solar time. This determination is correct within a small fraction of a second; and may serve to give value to observations made by other observers, who took the precaution to accurately note the instant of feeling the tremor, and to ascertain the error of their time pieces.

The following is a summary of the reports of the officers of Engineers who made the observations at the several stations—arranged in the order of their increasing distances from the mine.

Lieut. Young at Fresh Pond Junction—distant 5.134 miles from the mine. By an unfortunate accident, the register was not running at this station; and the time results being noted by a watch, are only approximate. Lieut. Young reports: "Very shortly after the mine signal we felt quite a distinct tremor in the ground under us, and at the same time heard a low rumbling sound exactly similar to the first sounds heard after the explosion of a dynamite torpedo. The time between the mine signal and the tremor, was about seven seconds; and the duration of the tremor as shown by the seismometer was about sixty-three seconds. The rumbling sensation lasted several seconds."

Lieut. Griffin at Willet's Point—distant 8.33 miles from the mine. These observations were perfectly successful. Lieut. Griffin was provided with an instrument of the B type. He reports:

"The first evidence of the explosion was a sudden and very violent shaking of the mercury. The maximum effect *seemed* to be reached at once, and not gradually; but, as the first shake was so violent it is *possible* that the maximum may not have been instantly attained, for a slight increase or diminution in the disturbance could not possibly have been perceived at that time.

The motion of the mercury subsided quite rapidly to a regular vibration which lasted for several seconds.

The vibration as it appeared in the mercury, may be shown by the following curve (plate II). This is designed to indicate that for some time it was impossible to distinguish any distinctive feature of the vibration except the fact that it was violent. Then it gradually began to subside. This subsidence *increased* in rapidity up to a certain point and then *decreased*. After this the mercury settled down very gradually.

I thought I heard the noise of the explosion simultaneously with the first vibration. It sounded something like a torpedo, but more muffled and with more of a rumble, and, so to speak, roar to it. In this I may possibly have been mistaken, as none of the bystanders noticed it."

Measurements on the register paper showed that the first tremor was noted at 5.3 seconds after the explosion; that the violent agitation continued for 37.1 seconds, and that it continued perceptible for 35.2 seconds more—making a total period of 72.3 seconds during which the mercury was sensibly shaken.

Lieut. Kingman at Jamaica—distant 9.333 miles from the mine. Everything at this station worked admirably. The instruments were placed in an old foundry where the earth was very hard. Lieut. Kingman reports: "A click of the armature informed me that the circuit had been closed at Hallet's Point. Following this came the vibration of the earth—sharp, strong and unmistakable. The vibration was distinguishable for a period of about thirty seconds, decreasing in violence from the first, and growing less and less until it finally could no longer be detected. If I were to represent the intensity of the shock by a curve, it would take a form like the right hand figure on plate II, the ordinates being the intensity, and the abscissas the time. There was a short period of intense vibration, which decreased rapidly, at first, and then slowly and uniformly to zero.

"Accompanying the shock was a low rumbling sound of about three or four seconds duration, which was distinctly heard by me, and also by a portion of the bystanders; there were some, however, who did not hear it. The sound and the shock came together, and the sound was loudest when the vibration was at its maximum. Though I listened intently for more than a minute after the explosion, no other sound of this character was heard; and I am satisfied that it must have been caused by the mine, for it was entirely similar to the sound of a torpedo when heard at a distance.

"In preparing to observe the shake I had focused my telescope on the reflected image of a horse-hair fastened to the glass cover of my artificial horizon. This image happened to be placed in the direction of wave propagation. On the arrival of the shock, this image became distorted into an undulating line. The undulations seemed to start from the end towards Hallet's Point, and run along the hair and then return; causing the image to present the appearance shown on the left hand figure of plate II. It could be distinctly seen in each of its different positions."

The register paper showed that the interval between the explosion and the arrival of the tremor was 10.9 seconds; and that the latter continued 23.5 seconds—the instrument being of type A.

Lieut. Leach at Springfield Junction—distant 12.769 miles from the mine. Here, too, the observations were everything which could be desired. The instrument was of the B type, which, it will be remembered, is doubly as sensitive as that used at Jamaica, and the same as that used at Willet's Point. Lieut. Leach reports:

"The soil in the vicinity of my station is a light sand, with a top-soil not more than six-inches in thickness.

"The place selected for the instrument was in a lane where the travel had been sufficient to kill the grass, and firmly pack the top-soil, but not to cut through it.

"I removed a little loose earth with a shovel, and then ground the artificial horizon into a firm contact with the solid earth.

"As soon as the warning message was received, I put the line to ground East, and connected my local wires to the relay and battery in the telegraph office. I then went to the instrument, repeated the tests, and at three and a half minutes before the appointed time, set the register in motion.

"At 2.51 P. M. by my watch, a click or rather series of clicks were heard on the register. This was the signal communicated by the firing of the mine, and its record on the paper was exactly like two "a"'s of the Morse code. Five seconds after, another mark was registered on the paper, the cause of which must have been an accidental closing of the main line or of my key—which, I am unable to say. About thirteen (12.7) seconds after the firing signal, the shock reached my station. As indicated by the seismometer, it was very violent, and seemed to attain its maximum instantaneously.

"The amplitude of the vibration of the reflected image of the object wire was very much greater than the extent of my field; across which, the rapidly vibrating wire images appeared but a thick haze.

"For this reason I am unable to give a positive opinion as to the violence of the shock when at its greatest intensity, which would readily result were the greatest amplitude known.

"But from the time the limits of vibration came within the field, I studied them as closely as the circumstances would permit.

"The instant that I saw the wires re-enter the field, is given by my 2nd mark at 19 seconds after the firing signal, and the end of the vibration is indicated by my 3rd mark at 31.67 seconds from the firing signal. During this interval, my conception of the subsidence is represented by the following curve, (plate II).

"The full line represents the portion of the vibration which was in the field, and which I was able to observe. I have completed the curve according to the same law, and think it may be accepted as a close approximation to the greatest intensity, and subsequent decrease, up to the time at which I began to note the vibrations themselves.

"The vibrations showed most unmistakably the peculiar wave oscillation which has been so frequently noticed in connection with shocks produced by exploding dynamite.

"I think the distance of the instrument from the explosion was far within its limit for that shock, and believe it could not have failed to register the latter at two and a half or three times the distance.

"The time at which the sound reached my station was not recorded, as the rain beating upon the tent prevented me from hearing it; but I had instructed my men, and had requested the bystanders, to listen sharply for it. A mean of their opinions would indicate that some sound certainly reached us; but the original wave had probably been completely dissipated, leaving only a superposition of echoes. At any rate, the result was a low rumbling sound which gradually increased to a maximum, and then as gradually died away. A large majority of those who were listening declared that they heard it."

The cause of the two letters, and of the subsequent mark (forming the letter T) to which Lieut. Leach refers is curious. They are duplicated on the Jamaica record, and Lieut. Young noticed their sound at his station. The paper at the firing station showed a continuous mark for the whole time occupied by the "A A". These facts prove that the tremor of the earth at the Astoria office, about 800 yards from the mine, was sufficiently violent to move the contact point of the relay; and the explosion thus actually sent a message consisting of the three letters A. A. T. down the line. The diagram (plate II) is a fac simile of the register records at the three stations, carefully plotted to a scale. The mark at the firing station, 1.1 seconds long, began at the closing of the circuit by the fall of the drop; it ceased when the circuit was broken by the withdrawal of the plug in the hands of the observer, which occurred when the jet apparently had reached about half its extreme height (125 ft.). No better evidence of the instantaneous nature of the explosion can be desired.

Lieut. Bass at West Point—distant 52 miles. Lieut. Bass had intended to observe with a magnifying power of twenty diameters, but the storm forced him to make use of a smaller glass having only a power of five.

He selected an admirable station among the hills, resting the mercury upon a ledge of solid rock, and observed intently for forty minutes in a pouring rain—thus establishing that no tremor observable with his instrument extended to that distance. This result, as already stated, confirms the accuracy of the empirical formula which indicates 33 miles as the limit. Probably a power of twenty would have detected a tremor.

ANALYSIS OF THE RESULTS.

The measurements upon the tremor caused by the blast at Hallet's Point, just described in detail, indicate a rate of movement far in excess of that reported by Mr. Mallet, and higher than might be anticipated from existing data upon the velocity of sound through solids. The most careful attention was, therefore, given to eliminating all possible causes of error. The distances were taken by Lieut. Leach from the manuscript maps of the railroad surveys, drawn upon a large scale, and from the published Coast

Survey maps, and may be depended upon as nearly correct. The time measurements, as already explained, are certainly inferior in precision to none that have ever been attempted in this kind of investigation The following consolidated table, which exhibits the results in a form convenient for reference and comparison, must, therefore, be accepted as trustworthy, although in some respects surprising.

Station.	Distance from mine.	Type of instrument.	Tremor of earth.		Velocity of transmission.
			arrived in	lasted for	
	miles.		seconds.	seconds.	feet per second.
Fresh Pond Junction.	5.134	A.	7.0 ?	63.0 ?	3873 ?
Willet's Point.	8.33	B.	5.3	72.3	8300
Jamaica.	9.333	A.	10.9	23.5	4521
Springfield Junction.	12.769	B.	12.7	19.0	5309

Certain observations upon the shocks produced by dynamite torpedoes, made before the blast at Hallet's Point was fired, also indicate a very high rate of transmission.

Thus, on August 18, Capt. Livermore, of the Engineers, made observations upon the explosion of a 200 lb. dynamite torpedo, planted 30 ft. under a floating iron target in 42 ft. water off Willet's Point. His station was 5 miles distant, nearly in the prolongation of Little Neck bay. He perceived the tremor distinctly with an instrument of the B type, reporting as follows: "The first indication of the explosion was given by the seismometer. The second was by the appearance of the jet of water to privates Newburg and Jones, the jet being at full height (110 ft.) when first seen. The mercury continued to vibrate after these men had called 'time' for at least one second. The disturbance was equal to that from a stone, the size of a man's head, dropped from a height of 6 ft. at a distance of 15 ft.; but the duration was very different, having an increasing and decreasing phase very perceptible"

The exact second of firing the torpedo was noted upon a chronometer with which Capt. Livermore's watch was compared before and after the explosion; and the beginning of the tremor was noted on this watch. The difference proved to be about 5 seconds, which was much less than had been anticipated. Still, the fact of the tremor being felt before the jet had subsided, established the substantial accuracy of the record.

In like manner, the time required for the tremor caused by a 100 lb. dynamite torpedo to reach Fort Schuyler, across East river, was noted a few days later by Lieut.

Greene of the Engineers. On this occasion the explosion was made to record itself with precision through an insulated torpedo cable, in a manner similar to that used at Hallet's Point; and the result indicated 4800 ft. per second as the rate of transmission of the shock.

Notwithstanding all this evidence, I sought to find a satisfactory reason to account for the extraordinary discrepancy between my results and those of Mr. Mallet; whose reputation in earthquake investigations, both as an observer and as a theorist, is so well established. He reported the velocity of transmission of artificial impulses to be in sand, 825 ft.; in discontinuous and much shattered granite, 1306 ft.; and in more solid granite, 1665 ft. per second. Also, from observations upon the explosion of large mines of powder in the quarries at Holyhead, he states: "the mean lowest rate of wave transit in these rocks through measured ranges of from 5038 to 6582 ft. was 1089 ft. per second; and the mean highest, 1352 ft. per second: and the general mean 1320 ft. per second." As all my data referred to explosions of dynamite, and his to gunpowder, I finally determined to try one experiment with the latter.

Accordingly on Oct. 10, I fired a charge of 70 lbs. of mortar powder in a wooden torpedo case, 5 ft. below the surface in 13 ft. of water. Capt. Miller and Lieut. Kingman, of the Engineers, were stationed at a distance of about a mile, the former with a telescope and key to close a register circuit when he saw the flash of a gun, to be fired by the same current which exploded the torpedo, and the latter with a seismometer of type A and a key to close the circuit when the mercury became agitated. The observation was perfectly successful, the time of transmission being 5.8 seconds for 7200 ft.—indicating a velocity of 1240 ft. per second. Hence, since 2100 ft. of the route lay through water, this gunpowder explosion accorded fairly with the gunpowder results obtained by Mr. Mallet.

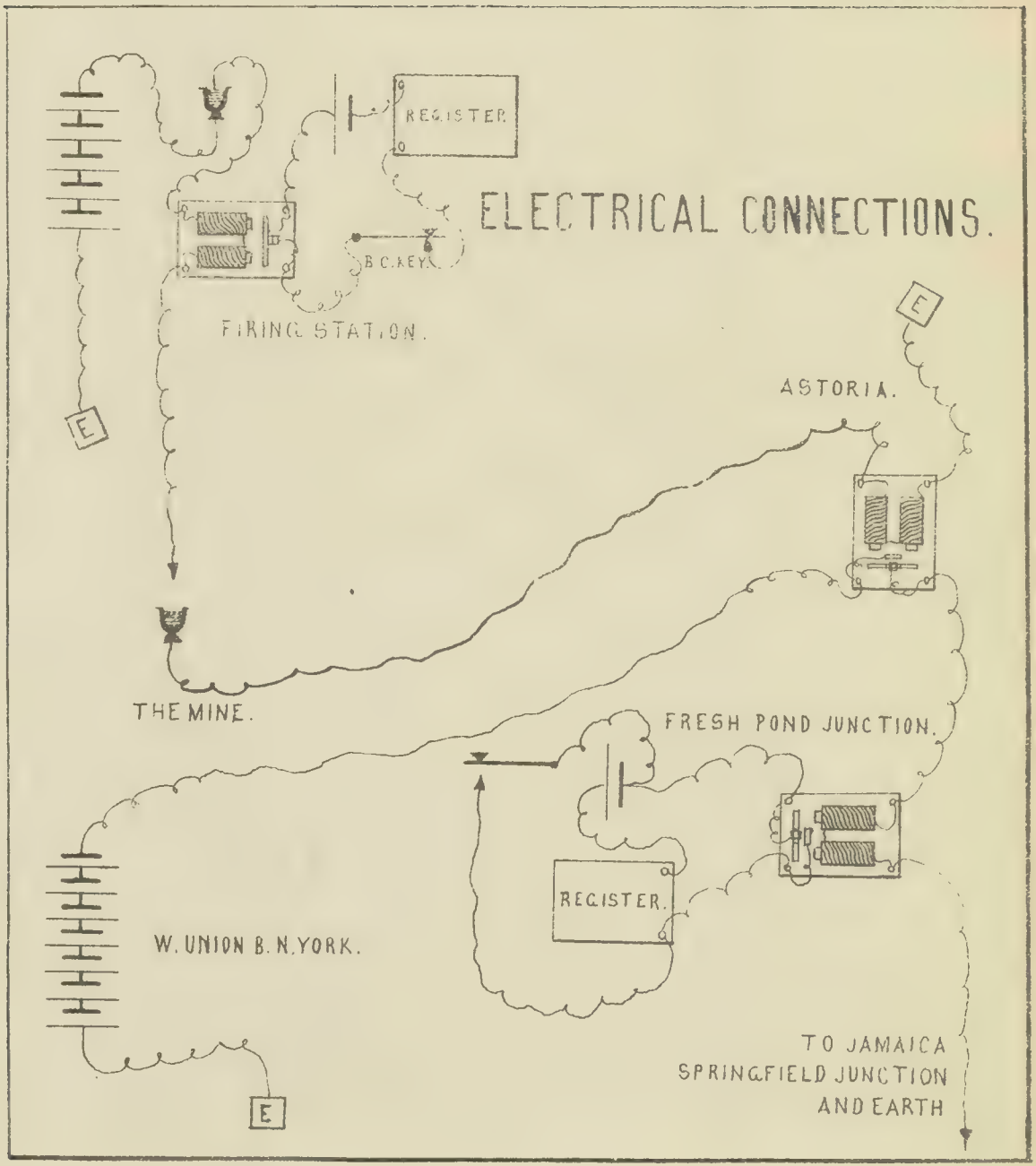
At first sight these facts would seem to indicate that the shock given by an explosion of dynamite is transmitted much faster than one from an explosion of gunpowder. Although the character of the impulse is widely different in the two cases, such a proposition certainly cannot be accepted without further evidence—although it is not novel. In a note to Silliman's Physics, it is stated: "Rev. E. S. Earnshaw, of Sheffield, England,* lately brings good evidence, both mathematical and physical to show that the accepted views stated in § 343 are correct only for sounds having no very great difference of intensity. The velocity of sounds of all kinds is a certain function depending upon the rapidity and length of vibration. In the case of violent thunder, the numerical value of this function becomes much greater than for ordinary sounds. These, and other remarkable conclusions, are sustained by mathematical reasoning. The author of the memoir

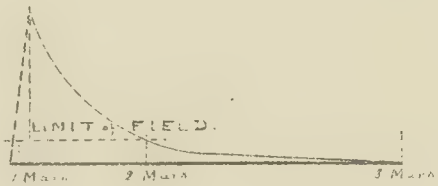
* London, Edinburgh and Dublin, Phil. Mag. from June, July, Sept., 1860.

also cites evidence to show that the crash of violent thunder claps has been often heard almost simultaneously with the flash of lightning, although the stroke fell several miles distant." Capt. Handbury, of the Engineers, also informs me that on one occasion when approaching a battery at drill, about a third of a mile distant, he heard the explosion of the gun and distinctly after it, probably as much as a second, the command to fire. This occurred at West Point, N. Y. A similar fact was noted on Perry's second voyage.

Nevertheless, since these observations have revealed the fact that the tremor consists of a long continued succession of earth waves lasting for many seconds, I am more inclined to accept a suggestion of Lieut. Kingman, who noticed at the gunpowder explosion that the movement was very slight, and only continued for an instant, showing that his seismometer was near the limit of its range. He suggests that if there be a gradual increase followed by a gradual decrease in the amplitude of the earth waves, a delicate seismometer will detect the arrival sooner than one less sensitive. In other words, the vibrations will begin sooner, as well as last longer, for such an instrument. This would apparently reduce the time of transit, and thus increase the measured velocity, when instruments of high power are employed, as at Willet's Point and Springfield Junction.

In fine, the extraordinary duration of the vibrations produced by these dynamite explosions, and especially by that of the great blast as noted at Willet's Point, to which the shock had both a water and a land route, is certainly a novel feature in artificial impulses; and, in connection with the hardly less extraordinary velocity of the general wave front, well merits attention. The latter is the more surprising, because Long Island geologically belongs to the drift formation; and is, of course, far from homogeneous in structure. It is, therefore, proposed to continue the investigation next spring, taking advantage of certain torpedo explosions which will be required in prosecuting the course of experiment now in progress at the School of Submarine Mining, at Willet's Point.

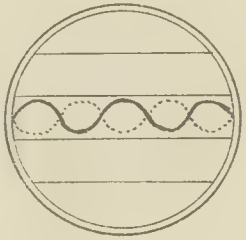

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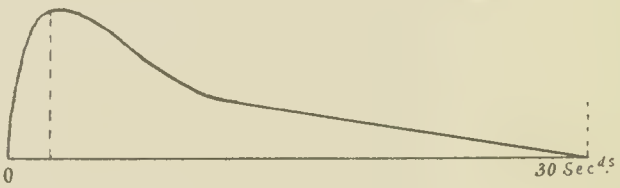


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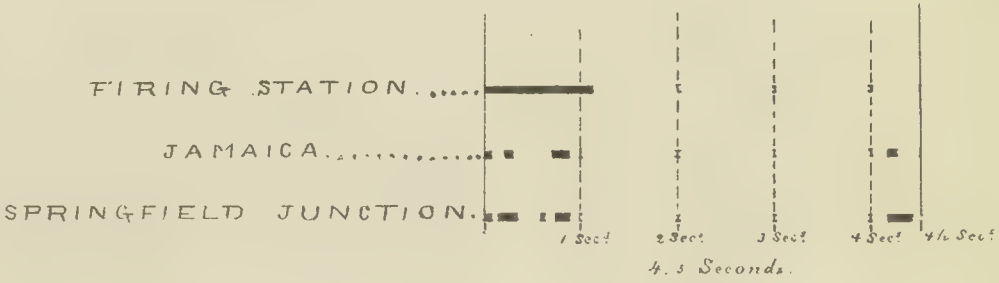
Lt GRIFFIN.





Lt KINGMAN.

REGISTER RECORDS.



LOCAL DEFLECTIONS

OF THE PLUMB-LINE

NEAR THE 49TH PARALLEL.

READ BEFORE THE ESSAYONS CLUB OF THE CORPS OF ENGINEERS,

NOVEMBER 14, 1876;

FROM

LIEUT. F. V. GREENE,
CORPS OF ENGINEERS.

NO. XLI. PRINTED PAPERS.

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STATION ERRORS NEAR THE 49TH PARALLEL.

A paper read* before the "ESSAYONS CLUB" of the Corps of Engineers, on Nov'r 14th, 1876, from Lieut. F. V. Greene, Corps of Engineers.

The object of this paper is to give some account of the deflections of the plumb-line along a portion of the 49th parallel, as deduced from a connection of the astronomical and geodetical observations made in the survey of the Northern Boundary line of the United States.

The tracing of a parallel of latitude affords unusual opportunities for a discussion of this sort, because the element of uncertainty in regard to the earth's figure is entirely removed. The latitude factor in our geodetic computations is always less than 5″, and the value of 5″ in feet is substantially the same whether we use Bessel's, Clarke's or Pratt's spheroid. As the deflection-results then depend solely upon the accuracy of the observations, I shall first give a short statement of the methods of survey used by the Commission, and form an estimate of the accuracy of their results.

Between the two monuments marking the 49th parallel, on the western shore of the Lake of the Woods and on the summit of the Rocky Mountains, is a distance of $853\frac{32}{100}$ miles, equivalent to 18° 54′ of longitude. In this distance, at average intervals of 21.3 miles, there were 41 astronomical stations, at each of which a point of the parallel was determined by observations for latitude with the Zenith Telescope. Adjacent astronomical stations were connected geodetically, and intermediate points of the parallel determined, by the method of tangents and offsets.

Of the 41 astronomical stations 4 were observed jointly by the United States and British Astronomers, 17 were observed by United States parties alone, 19 by British parties alone and 1—on the summit of the mountains—was observed jointly by the Northwest Boundary Commission in 1860–61.

The star-places used by the British Astronomers were derived solely from the vari-

* Also read before the Philosophical Society of Washington, May 20th, 1876; and published with the approval of Major W. J. Twining, U. S. Engineers, Chief Astronomer, Northern Boundary Commission.

ous Greenwich Catalogues; with an average of 81 observations at a station they gave a mean probable error in the latitude of $\pm$ 0.″088. The American Astronomers used their own star Catalogue, which was constructed by selecting the places given in all the trustworthy catalogues, from and including Bradley's, and deducing therefrom the most probable value of each declination. With an average of 76 observations at a station, the mean probable error of the latitude was $\pm$ 0.″059; the latitude given by the observations of a single night differed from that of another night at the same station by a quantity, whose mean value was $\pm$ 0.″22. At the four joint stations the latitude deduced independently by the two parties differed by 0.″29 0.″28 0.″07 and 0.″27 respectively.

From the character of the work as shown by these results, I think it is safe to say, that no astronomical latitude is in error by an amount exceeding 0.″15.

The geodetic work consists in tracing the arc of a great circle, perpendicular to the meridian of departure, from one station to the next (taking careful azimuth observations at each extremity), and in measuring offsets from this great circle or tangent, to the parallel; these offsets being computed by the usual geodetic formulæ. At the terminal stations the computed offset never agreed with the distance from the great circle to the point of the parallel determined astronomically. The amount of this discrepancy we have been in the habit of calling the "Station Error"; it evidently consists of the meridional component of the local deflection of the plumb-line plus or minus all the errors of observation, both astronomical and geodetic. The estimated error in the astronomical work I have given above, and I will now show the errors of the geodesy, which were in the azimuth observations and in the tracing of the tangent.

The azimuth observations were made with an 8 inch Würdemann theodolite on circumpolar stars near elongation, and gave a mean probable error, with 40 observations on 4 stars, of $\pm$ 1.″8; the uncertainty is probably 10″. The observations at the terminal points of the tangents showed them to have an average error in azimuth of 28.″7; as it was impossible to ascertain the point or points where this error had been made, it was adjusted by considering the whole line to have been in error by 14.″3, which in a length of 20 miles corresponds to an error of 9½ feet in latitude at the terminus.

If then all the errors of observation were in the same direction, their sum would be equal to about 25 feet; and it is safe to say, that the "Station Errors" deduced in the manner above described, represent the absolute meridional deflection of the plumb-line with an uncertainty at any point of 40 feet, or 0.″4.

In the following table, the column D contains the "Station Errors", or the discrepancies between each astronomical determination of the parallel and the mean parallel; the mean parallel is that with reference to which the sum of the discrepancies north is

equal to the sum of those south; its position is determined by referring all the discrepancies to one station and dividing their algebraic sum by 41.

STATION ERRORS NEAR 49th PARALLEL.

Stations.	D. Station errors mean parallel = 0.	A. Computed deflections 1 to 10 miles.	B. Computed deflections 10 to 40 miles.	D − (A + B) Unexplained deflections.
1	− 2.31		− .007	− 2.30
2	+1.52		0	+1.52
3	+2.33		0	+2.33
4	+3.18		− .15	+3.43
5	+3.50		− .23	+3.73
6	+2.95	− .42	− .27	+3.64
7	+2.22	− .09	− .46	+2.77
8	+1.40		− .36	+1.76
9	− .21		− .54	+ .33
10	− 1.78	− .09	− 1.16	− .53
11	− .78	− .15	− .74	+ .11
12	+ .06		− .65	+ .71
13	− .30		− .46	+ .16
14	− 1.91		− .68	− 1.23
15	− 2.23		− .83	− 1.40
16	− .50		− .92	+ .42
17	− .31		− 1.07	+ .76
18	− .94		− .99	+ .05
19	+1.77		− .38	+2.15
20	− 1.91		+ .10	− 2.01
21	− .81		+ .80	− 1.60
22	+ .98		+1.50	− .52
23	− .76		+1 90	− 2.66
24	+1.54		+3.29	− 1.75
25	+2.00		+2.16	− .16
26	+3.55		+2.85	+ .70
27	+3.03		+2.80	+ .23
28	+1.61		+2.03	− .42
29	+5.94		+1.38	+4.56
30	+4 30		+ .99	+3.31
31	+2.09		+ .95	+1.14
32	− .67		− 1.43	+ .76
33	− 5.32	− 2.31	− 1.77	− 1.24
34	− 7.95	− 7.25	− 1.37	+ .62
35	− .67		− 1.04	+ .37
36	− .52		− 1.00	+ .48
37	− 1.17	?	?	
38	− 3.42	?	?	
39	− 6.09	?	?	
40	− 2.42	?	?	
41	− 1.00	?	?	
σ	43.97 43.98			36.″08 15.″82
Means.	2.″146			1.″442

It will be noticed, that the first and last stations (Nos. 1 and 40) observed by this

commission differ from each other by only 0.″11 in latitude although 346 miles apart; the least discrepancy between adjacent stations is between Nos. 35 and 36, where at a distance of 24.6 miles from each other, the astronomical latitudes differ only 0.″15; the largest discrepancy is near the Sweet Grass Hills between Nos. 34 and 35, where the latitudes differ by 738 feet or 7.″28. The most northerly (No. 29) is nearly14″ north of the most southerly (No. 34). The mean deflection is 2.″146.

These results are shown more clearly on the accompanying diagram. The upper figure represents a profile of the country constructed from observations with the mercurial barometer at the astronomical stations and from trigonometric levelling in the intermediate points; the lower figure shows the main features of the topography for a distance of forty miles on each side of the line, including the approximate contours for vertical distances of 200 feet, which were necessary in order to calculate the deflections. The data for these contours were found in the barometric altitudes, the stadia surveys near the boundary and the reconnaissances at greater distances, and in the estimated fall of certain rivers along which three or more altitudes are known. These contours make no pretence to accuracy greater than that required for my purpose, viz.: to calculate the deflections within 0.″4. The middle figure is a representation (exaggerated more than 200 times) of the relative positions of the astronomical and mean parallels. The scales are given for each figure.

Having given the actual deflections it now becomes interesting to see how far these can be accounted for by the attraction of masses above the surface, and how many of them must be referred to some attracting force under ground, where, as Pratt says, "we seem to have an unlimited resource upon which to draw, to explain any anomalies of local attraction we may perceive on the surface"

The formulæ which I have used for calculating the deflections are those deduced by Lieut. Col. A. R. Clarke, R. E., of the British Ordnance Survey; the whole discussion is found at length in his "Account of the Principal Triangulation" pp. 576-630, but I shall merely give an outline of the manner in which the deduction is made.

"The plumb-line is acted upon by gravity G in a vertical direction, and by the disturbing force A acting in a horizontal direction; the resultant of these forces $= \sqrt{A^2 + G^2}$ acts in a direction which makes the angle $\tan^{-1} \frac{A}{G}$ with the direction of gravity. When A is very small in comparison with G, this angle is identical with its tangent." Using Airy's expression for gravity, Clarke shows that

$$\phi = 12.''447 \frac{A}{\delta} \qquad (1)$$

in which ϕ is the deflection caused by an attraction A, and δ is the mean density of the earth.

In order to find the value of A the ground in the vicinity of the station is divided into compartments by a series of radii and circles; and the attraction of one of these compartments is found to be:

$$A = \rho (r' - r_{,}) (\sin \alpha' - \sin \alpha_{,}) \frac{h}{r} \qquad (2)$$

in which: ρ is the mean density of the compartment.
h the mean height of the compartment.
r' and $r_{,}$ the bounding radii.
α' and $\alpha_{,}$ the azimuths of bounding radii.

$$r = \frac{r' + r_{,}}{2}$$

It would be extremely inconvenient to compute the attraction of each compartment separately, and the form of (2) immediately suggests a law of division of the lengths and directions of the radii, which will avoid this, and make the second member of the form, constant $\times h$. This law evidently is to make the lengths of the radii in arithmetical progression and their directions such that their sines shall be in arithmetical progression.

Denoting then by (r) and (s) the common difference respectively of the lengths of the radii and the sines of their azimuths, and by Π_n the sum of the mean heights of all the compartments between the n^{th} and $n + 1^{\text{th}}$ circles on the north, and by Π'_n the same on the south, we have:

$$\Sigma A = \rho (s) \Sigma \frac{\Pi_n - \Pi'_n}{n + \frac{1}{2}} \qquad (3)$$

and consequently:

$$\psi = 24.''894 \frac{\rho}{\delta} (s) \Sigma \frac{\Pi_n - \Pi'_n}{2n + 1} \qquad (4)$$

$\frac{\rho}{\delta}$ may be taken at $\frac{1}{2}$ since the average specific gravity of rocks varies from 2.5 to 3.0, and the mean density of the earth is about 5.5. If the radii are so drawn that their azimuths are $\sin^{-1}\left(\frac{1}{10}\right)$ $\sin^{-1}\left(\frac{2}{10}\right)$, etc., (s) becomes $\frac{1}{10}$; and if Π_n, etc. be expressed in feet the formula becomes, for $n + 1$ circles:

$$\psi = 0.''00023574 \left(\frac{\Pi_1 - \Pi'_1}{3} + \frac{\Pi_2 - \Pi'_2}{5} + \cdots\cdots + \frac{\Pi_n - \Pi'_n}{2n + 1}\right) \qquad (5)$$

In order to use this formula contoured maps are necessary for finding the mean heights; our stadia surveys supplied these maps in the immediate vicinity of the station, and for distant attractions I have used the 200 feet contours on the accompanying diagram.

In the preceding table the system of deflections A was calculated with radii whose common difference was 1 mile, and which extended from 1 to 10 miles, except at station 34 where the common difference of the radii was 2000 feet. The system of deflections B was calculated with radii, whose common difference was 10 miles, and which extended from 10 to 60 miles. Deflections A have been calculated at only six stations—those, namely, in the vicinity of the Pembina and Turtle mountains, and the Sweet Grass Hills. All the other stations from 1 to 36 are surrounded, in their immediate vicinity, by level plains, only broken here and there by the gorge of a stream; the maximum deficiency of attraction of any one of these ravines is 0.″3, and this is less than the estimated uncertainty of the numbers in column D.

Beyond station 36, and in the Missouri Coteau, we have not sufficient data for contours.

It may seem strange at first, that the distant attractions should be so much larger than those nearer the station; but this must always be so in a country like the plains east of the Rocky Mountains, where there are few abrupt irregularities, but where large tracts of country have a gradual tilt in the direction of the drainage. For instance, let us suppose a tract of country with a radius of sixty miles, which has every where a uniform slope to the north of only 2 feet in a mile; the plumb-line at the centre of this tract will be deflected less than 0.″04 by the attraction within the 10 mile circle, but 0.″36 by that between the 10 and 60 mile circles.

By inspecting the table given above, we see, that some of the observed deflections are accounted for by the irregularities of the surface, and some are not.

The column D − (A + B) contains the unexplained deflections, the mean of which is 1.″442, or about two-thirds the mean of the observed deflections. Only one-third of these deflections is then accounted for by the irregularities of the surface. If we correct the latitudes by the deflections A + B, the mean parallel will be 0.″39 north of its present position.

Let us now examine these deflections more in detail. At the Lake of the Woods no systematic soundings were taken, and hence we can not apply the formulæ. A few soundings, which were taken by the British parties, gave a very shallow depth—never more than 18 feet. Assuming a mean depth of 20 feet, the formula gives a deflection of 0.″007. But as the mass (or in this case the deficiency of mass) is directly proportional to its depth, it would require a mean depth of 150 feet to produce a deflection of 1″. It is evident, therefore, that the lake can only account for a small portion of the deflection at this station, which is 2.″31 south of the mean and 3.″86 south of the next station. This deflection must then arise from some causes beneath the surface.

The geological matter on the accompanying diagram I have taken from the report of Mr. George M. Dawson, Geologist to the British portion of the Commission; it shows that the line of separation between the Eozoic and Paleozoic rocks passes through this station bearing N. 22° W., the Eozoic being on the north-east. If we take the density of the limestone of the Paleozoic at 2.8 and that of the gneiss of the Eozoic at 2.7, these being the figures given by Clarke, and assume the two beds to be each 4 miles thick and 100 miles in extent to the north and to the south, the resulting deflection will be about 2.″5 S., as calculated by one of Pratt's formulæ. I introduce this only as a *possible* explanation of this otherwise inexplicable deflection, and to show how a large deflection may be caused by a slight change in the density of rocks, extending over a considerable surface.

In the next 180 miles, in which there are 8 stations, the only visible cause of any appreciable deflection, i. e., larger than 0.″4, is at the second prairie plateau here called Pembina Mountain (and this is only 0.″7). In this distance, station No. 2 is surrounded by vast tamarack swamps; No. 3 is on a knoll rising about thirty feet above the swamp and of slight horizontal extent; No. 4 is in the midst of the Red River Valley, where the horizon is unbroken by a single elevation; No. 5 is similarly situated; No. 6 is at the base of Pembina Mountain; No. 7 is on the Pembina plateau just south of the gorge of the Pembina River, which, however, gives a deflection of only 0.″09; No. 8 is in the midst of a vast plain, as is also No. 9, where the plumb-line comes to its mean position. Now, by looking at the diagram of the two parallels, we see that throughout this 180 miles the astronomical parallel bends to the north in a curve of remarkable regularity—and as we have seen without any *visible* cause. The only reason which I can suggest in explanation of this, is geological, and derived from Mr. Dawson's map again. On this it will be seen that the Paleozoic beds, referred to above, give place near the Red River, station No. 4, to the Cretaceous, the strike being N. 40° W. This would give the Paleozoic a somewhat triangular area, cut near the apex by the boundary line. If the beds are of great thickness, and the difference of density is $\frac{1}{30}$ of the mean and in favor of the Paleozoic, these deflections can all be accounted for; although it is impossible to compute them accurately. Pratt has shown ("Figure of the Earth" p. 51) that the remarkable deflection of 8″ near Moscow can be accounted for by the supposition of a dyke 16 miles wide and of great depth, having a deficiency of density equal to $\frac{1}{39}$ that of the surrounding rock.

Passing along the line we come to stations 10 and 11, which are on the eastern and western slopes of an irregular mass of wooded hills and swamps known as Turtle Mountain. Its deflection is very nearly accounted for by the formulæ.

The next 140 miles of the parallel, in which are stations 11 to 18, pass over the great plain of the Mouse River, which is unbroken except by the ravines of the river and its branches. At most of these stations the deflection is insignificant, but at Nos. 14 and 15 there is a southern bend of about 2″ which can not be accounted for by anything in the geography or geology as far as known.

Beyond station 18 we come to the Coteau of the Missouri, a peculiar piece of topography, resembling an exaggerated cobble stone pavement more than anything else. The little hills of drift deposits, never more than 100 feet in height, seem to have been thrown together without any systematic arrangement, although the whole mass forms the watershed between the Missouri and Saskatchewan systems. Station No. 19 is in the midst of these hills. We have not sufficient data for contoured maps in this vicinity, and hence can not compute the deflection. But it is safe to say, that there is no mass in this neighborhood, which could cause a deflection of even 0.″5. The large northern deflection, 1.″77, observed here, is therefore inexplicable, as are also the southern deflections 1.″91 at station 20, and 0.″81 at station 21, both of which are in the opposite direction to what we should expect.

At station 22 the deflection is quite well accounted for, but at 23 it is in the wrong direction.

From station 23 to 32, a distance of over 200 miles, the parallel is south of the large broken plateau, which forms the watershed between the Saskatchewan and Missouri. Although not of great height, it covers a large horizontal extent and exerts a considerable attraction. The observed deflections agree reasonably well with what the formulæ give us to expect, except at Nos. 29 and 30, where no reason can be given for the large deflection to the north.

In the Sweet Grass Hills, the formulæ do not account for all the deflection at the East Butte, No. 33 and they account for too much at the West Butte, No. 34. Stations 35 and 36 agree reasonably well with what the formulæ give.

At the remaining stations I have not computed the deflections, because the contours are not trustworthy. We see, however, that the attraction of the Rocky Mountains gradually becomes stronger as we approach them, and finds its maximum at station No. 39; at this point the latitude observations were taken four miles north of the line, with the whole mountain mass to the south and a more or less open plain to the north and for 40° west of north.

Station 40 was in the midst of the mountains, which extended for about five miles to the north before the plains were reached. We, therefore, might expect the southern deflection to be less than at No. 39, as indeed it is.

Station 41 is symmetrically situated with reference to the mountain masses, and here we find the deflection reduced to a small quantity—one second.

The results of this investigation may then be summarized as follows. On the 49th parallel, between the 95th and 114th meridians, the average meridional deflection of the plumb-line is 2.″146. At 29 stations the deflections calculated from the irregularities of the surface are in the same directions as those observed, and at 12 stations they are in the opposite direction. The residual deflections unexplained by the irregularities of the surface have an average value of 1.″442, or about two-thirds of the whole deflection.

It is possible that these results might be modified by more extended and detailed topographical surveys, than it was possible for us to make consistently with our prime duty of marking the parallel beyond the possibility of dispute and without unnecessary expense.

A short synopsis of the history of this interesting subject of zenith deflections may not be out of place. It is little more than 100 years since the then Astronomer Royal of England made the celebrated experiments for mean density at the Schehallien hill. He found a station error of 11.″7 between the stations on opposite sides of the hill, and from this he calculated the mean density by this method of dividing the ground into compartments—the reciprocal of the problem before us. This was the first accurate determination of a station error, the previous experiments in Peru being untrustworthy.

The subject does not seem to have been much regarded in the measurement of the French arc, but not long afterward Beccaria's arc in Piedmont developed a most astounding error. The measurements and calculations were revised by the French Geographical Engineers in 1809, and they gave as a result a discrepancy of 47.″84 between the astronomical and geodetic amplitudes of an arc of only 1° 8′; the deflection at the northern station being 28.″09 N., and at the southern 19.″75 S.; the localities are in the plain of Turin and surrounded by the Piedmontese Alps.

In the last 50 years the subject has attracted considerable attention in the measurements of the arcs of meridian and the calculations resulting therefrom.

Bessel uses ten arcs in his discussion of the figure of the earth. I am not aware that he made any attempt to ascertain the deflections from the irregularities of the ground, but he found the mean error of a latitude to be 2.″64, i. e., he had to correct each latitude by that amount, in the average, in order to make it fit his ellipse. He assumes 1.″20 as the limit of error of observation, which would leave as the average *probable* local attraction $\sqrt{2.64^2 - 1.20^2} = 2.''35$.

In the Indian Survey, care was taken to place the stations in localities supposed to be free from local attraction, but these efforts were not altogether successful owing to a

lack of exact knowledge on the subject. The attractions on this survey have been investigated by Archdeacon Pratt, and are discussed in his "Figure of the Earth". Pratt calculates the attraction of the Himalayas, on a station 20 miles distant, to be 28″, but the observed deflection is only about 3″; various hypotheses have been offerred in explanation of this discrepancy and of the anomalous fact, that at many of the southern stations the deflection is *towards* the sea. In Bessel's discussion of the Figure of the Earth the largest correction to a latitude in India is about 4″.

The most satisfactory discussion with which I am familiar is that of Clarke, in the Ordnance Survey volume previously referred to. Clarke first deduces the axes of the spheroid, which, for the surface of Great Britain and Ireland, will make $\Sigma(\xi)^2+\frac{1}{6}\Sigma(\eta)^2$ a minimum, ξ and η being the corrections, which must be applied to his observed latitudes and longitudes. With these axes he calculates the geodetic latitudes of 15 stations, where the deflection has also been calculated from the irregularities of the surface. The average observed deflection (D) is 2.″05 and the average unexplained deflection (D − (A+B)) is 1.″35. The spheroid which he finally adopts, however, as most nearly representing the surface of Great Britain and Ireland, is obtained by correcting each of the 15 latitudes by the deflection due to the ground, and then making $\Sigma(\xi)^2+\frac{1}{6}\Sigma(\eta)^2$ a minimum. The mean observed deflection is now 1.″72, and the mean value of D − (A+B) is 1.″10.

Several anomalous results appear; in the Isle of Wight there is an unaccountable attraction *towards* the sea and away from the main land; at Greenwich and at a few other points the deflection is in the contrary direction to that, which the ground would indicate; at various stations the ground accounts for only half of the deflection, notably at a station on the north coast of Scotland, where the southern deflection is 10″, of which less than 5″ can be accounted for.

In this country the materials for investigating this subject must exist in the records of the Coast and Lake Surveys. I am only aware, however, of one discussion of the subject, that by Mr. Schott, in appendix No. 7 to the Coast Survey Report for 1869. This refers to the deflections at ten stations in the District of Columbia; the mean meridional deflection is 0.″77. The deflections due to the irregularities of the ground are not calculated.

In conclusion I wish to call attention to what is perhaps the most striking fact of this whole discussion, and that is the remarkable agreement in the values of the mean observed deflections; this seems to be always a little more than 2″—a quantity far in excess of

the errors of observation. Bessel, discussing the figure of the earth, with 40 latitudes observed in three continents, finds a mean error of 2.″64; Clarke, discussing the figure of the British Isles, with 37 latitudes, finds a mean error of 2.″05, of which 1.″35 can not be accounted for; and the result of our own investigations in making 850 miles of a parallel, with 41 latitudes, gives a mean error of 2.″15, of which 1.″44 can not be accounted for.

This close agreement at once excites inquiry as to its significance; if it prove anything at all beyond an accident, it would seem to prove that the heterogeneity of the earth's crust, for a tract of not less than 500 miles in extent, is substantially the same in amount in every part of the world; or, in other words, that the actual figure and density of the earth's crust differ from the mean figure and density within certain limits, and that the average amount of the variation at any one place is such as to produce a deflection of the plumb-line of about $2\frac{1}{4}$ seconds.

It will be of interest to see if these results are confirmed by the observations of the great geodetic survey now in progress on the continent of Europe.

A LIST

Of some of the Publications Referring to the Above Subject.

Delambre, J. B. J.—"Méthodes analytiques pour la détermenation d'un arc du méridién, Précédées d'un mémoire sur le même sujet par A. M. Legendre." Paris. An. VII. 4.

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(*a*) "Tagebuch der Gradmessung, geordnette Reinschrift." 3 Bände 1822–29. Fol.

(*b*) "Tagebuch der Basis-Messung bei St. Simonés 1827, geführt von W. Struve. Abschrift nebst Zusammenstellung aller Massvergleichungen, 1827–29." 4.

(*c*) "Tagebuch der Basis—Messung bei St. Simonés 1827, geführt von W. v. Wrangell Abschrift." 4.

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Struve, W.—"Beschreibung der Breitengradmessung in den Ostseeprovinzen Russlands, 2 Theile, nebst Kupfertafeln." Dorpat, 1831, 4. 3. Vol.

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"The Figure of the Earth." By John H. Pratt, Archdeacon, etc. 5th Edition 1873.

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"Paper by Charles A. Schott, on the local deflections of the Zenith at points in the vicinity of Washington."

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"Publications of the Prussian "Geodätische Institut" on various subjects." 7 pamphlets, 1872–76.

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ABBREVIATIONS.

Paris, C. R. "Comptes rendus hebdomadaires des Séances del'Académie."
Paris.—"Mémoires de l'Académie des sciences de Paris."
Ph. Tr.—"Philosophical Transactions of the Royal Society of London."
Pétersb.—"Mémoires de l'Acad. Imp. des scienc. de St. Pétersbourg."
Zach.—"Zach. Correspondance Astronomique."
Schum.—"Astronomische Nachrichten."
Pét. Bull.—"Bulletin de l'Academie de St. Pètersbourg."

DIAGRAM

to illustrate the

RELATIVE ER[illegible] OF ASTRONOMICAL STATIONS IN LATITUDE

resulting from

LO[illegible] FLECTIONS OF THE PLUMB LINE.

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PROFILE

Horizontal Scale 1 inch = 30 miles 1900,800
Vertical Scale 1 inch = 1000 feet 48,000

DEFLECTIONS

Scale of abscissas 1 inch = 30 miles 1900,800
Scale of ordinates 1 inch = 8" of lat. = 810.72 feet 9729

TOPOGRAPHY

Scale 1 inch = 30 miles 1900,800

Mean Parallel
Astronomical Parallel
Cypress Hills
Rocky Mountains
Milk River
Sweet Grass Hills
Wood Mountain
Porcupine Hills
Cypress Hills
Missouri River
Moose River
Pembina Mountain
Red River
Lake of the Woods
Astronomical Parallel
Mean Parallel

TWO LEVELS

IN THE

ZENITH TELESCOPE METHOD.

READ BEFORE THE ESSAYONS CLUB OF THE CORPS OF ENGINEERS,

NOVEMBER 14, 1876;

FROM

LIEUT. T. N. BAILEY,
CORPS OF ENGINEERS.

NO. XLII. PRINTED PAPERS.

Printed on the Battalion Press.
Sergt. Carmichael & Pvt. Wade, Printers.

TWO LEVELS IN THE ZENITH TELESCOPE METHOD.

A paper read before the "ESSAYONS CLUB" of the Corps of Engineers, on November 14th, 1876, from 2nd Lieut. T. N. Bailey, Corps of Engineers.

The object of this paper is to explain a method of employing an extra level in Zenith Telescope (latitude) work, in such a way as to materially increase in number the pairs of stars possible to observe per hour. I followed this method in determining the latitude of secondary stations while on the Lake Survey, season of 1875, by authority from General Comstock, Corps of Engineers; and, as far as my limited information extends, it is original with me.

The instrument used was a portable "broken transit," or one with the eye-piece at the end of its horizontal axis; it was 24.5 inches in focal length, and was supplied by Pistor and Martin, Berlin.

It was employed both in time and latitude determinations, and was furnished with two equally sensitive setting or latitude levels.

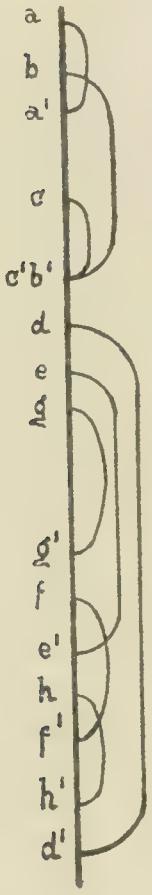
The method is as follows: suppose four stars in this order of right ascension, A*n*, B*n*, A*s*, B*s*—A*n* and A*s* forming a pair, and B*n* and B*s* another pair, *n* and *s* indicating north or south stars.

Set level A for the pair A*n* A*s*, and level B for the pair B*n* B*s*. Observe the star A*n*, reading the micrometer and level A; then, as the position of level A referred to the line of sight will not be changed, the telescope and levels may be moved together in altitude to observe the star B*n*—recording micrometer and level B. Turn the instrument 180° in azimuth and observe similarly A*s* and B*s*, when all data for two separate pairs will be obtained. Level A may be reset for a third pair after the star A*s* has been observed; or stars may come in the order A*n*, B*s*, B*n*, A*s*, etc.

The essential condition in Zenith Telescope work being that the position of the level referred to the line of sight shall not change between observations on the constituents of a pair, and this condition being liable to be violated without detection by alterations from

temperature and other changes and jars from handling the instrument, it is evident that the probability of this condition being closely satisfied, is greater as the interval of time between the stars of a pair is less, and as the displacements from handling the instrument are reduced. Now the latter can be diminished by the care of the observer, while over the former he has no control; from which it appears that a gain in accuracy will result from this method of crossing the pairs when the interval of time between the constituents is considerable, but two such crossed pairs would not be as valuable as the pairs A*n* A*s*, B*n* B*s*, observed in the same space of time.

In selecting stars I would recommend that every possible pair permitted by adopted limits be roughly represented by looping points of a line, these points corresponding to the right ascension of the stars forming the different pairs.



The most favorable pairs can then be readily selected by inspection. To illustrate, let right ascension be estimated from a towards d', then represent roughly at a and a' the positions in scale of right ascension of the two stars of a pair; these points joined by the loop will indicate the possible pair $a\ a'$; represent similarly the pairs $b\ b'$, $c\ c'$, etc. By inspection it is seen that it would be preferable to select the pairs $a\ a'$ and $c\ c'$, rather than $a\ a'$ and $b\ b'$; also $f\ f'$ and $h\ h'$, would be better than either one only. It is also seen that if all possible pairs were not examined, only three $a\ a'$, $c\ c'$ and $d\ d'$ might be selected. The greatest number of pairs which could be observed with a single level from this group would be four, while by crossing the pairs seven could be observed. The choice of pairs will also be influenced by considerations of magnitude, suspicious declinations, etc.

This method could be followed with the ordinary Zenith Telescope by the addition of an extra level.

If the single level method had been followed and both levels had been read for each observation, the gain in accuracy would only affect the level correction, and would be $= \sqrt{2}$.

From my observations at Howell, Mich., taking the probable error of declinations in Safford's Catalogue to be $= 0''.75$ I deduce the following:

Number of results, - - - - - - - - - - - - - - - - - 74.
Number of pairs, - - - - - - - - - - - - - - - - - 33.

Probable error of observation in the half differences of zenith distance, - - 0″.95.
Probable error of one resulting latitude from one pair, - - - - - - - - - - 1″.10.
Probable error of weighted mean, - - - - - - - - - - - - - - - - - - - 0″.13.

By comparing my season's work, using two levels, with the results of another observer using a single level, both employing the same catalogue at about the same latitudes, I found that the gain in number of pairs observed per hour was eighty-five (85) per cent.

It would seem that this method may be advantageous, partly from the gain in accuracy that will result from increasing the numbers of different pairs observed, and partly from the diminution in the time required to obtain a given number of observations, and the consequent greater precision in observing due to the increased physical comfort of the observer.

NOTES

ON

MAGNETIC DETERMINATIONS.

READ BEFORE THE ESSAYONS CLUB OF THE CORPS OF ENGINEERS,

MAY 22, 1877;

FROM

CAPT. C. W. RAYMOND,
CORPS OF ENGINEERS.

NO. XLIII. PRINTED PAPERS.

Printed on the Battalion Press.
Sergt. Carmichael & Pvt. Wade, Printers.

NOTES ON MAGNETIC DETERMINATIONS.

A paper read before the "ESSAYONS CLUB" of the Corps of Engineers, on May 22, 1877, from Capt. C. W. Raymond, Corps of Engineers.

In this note I propose to examine the theoretical errors in the determination of the inverse function of the Earth's Horizontal Intensity by deflections.

If two horizontal magnets, having their axes in the same plane, act upon each other, one being suspended and the other fixed, the equation of equilibrium will be:

$$\sin(\beta - \alpha) \iint \frac{u'(r-u)\,f(u)\,f(u')\,du\,du'}{[u'^2 + (r-u)^2 - 2u'(r-u)\cos(\beta-\alpha)]^{\frac{3}{2}}} = \varphi \cos\theta \sin\alpha \int u' f(u')\,du'$$

in which β = angle made by deflector (fixed magnet) with the magnetic meridian; α = angle made by suspended magnet with magnetic meridian; r = distance between centres of magnets in feet; u = distance from the centre of the deflector to any one of its transverse sections; $f(u)\,du$ = quantity of free magnetism in the section at a distance u from the centre of the deflector; u' and $f(u')\,du'$ = similar quantities for the suspended magnet. A particular case of this equation ($\beta - \alpha = 90°$) was deduced and discussed in my paper on the Theory of Terrestrial Magnetics.* It requires only a slight modification of that discussion to obtain the general equation given above.

If we make r sufficiently large compared with u and u', the last term in the denominator of the first member of this equation may be neglected. The equation may then be reduced as explained in my paper, and we shall obtain

$$\frac{m}{\varphi \cos\theta} = \frac{1}{2} r^3 \frac{\sin\alpha}{\sin(\beta-\alpha)} \left(1 - \frac{P}{r^2}\right) \qquad (1)$$

in which $m = \int u f(u)\,du$ = magnetic moment of the deflector, and P is constant for a given pair of magnets.

* Printed Paper, No. XX, 1872—Essayons Club.

This equation determines the value of $\frac{m}{\varphi \cos \theta}$ whatever may be the positions of the magnets with respect to each other, provided they are not in the same vertical plane. It is therefore important to select their relative positions so that errors of observation or adjustment shall produce the least effect upon the final result.

The relative dimensions of the two magnets may be so taken that $\frac{P}{r^2}$ shall be sensibly equal to zero. Representing $\frac{m}{\varphi \cos \theta}$ by χ the equation becomes:

$$\chi = \frac{r^3 \sin \alpha}{2 \sin (\beta - \alpha)} \qquad (2)$$

In determining the value of χ from this equation three errors are to be considered:

1. An error in the observation of α.
2. An error in the adjustment of β.
3. An error in the adjustment of r.

Other incidental considerations which affect the accuracy of the determination will be mentioned hereafter.

I shall first consider the effect of a very small error in each of the quantities separately; for it is evident that an error in one may be made without affecting the values of the others. The effect of an error may be either to augment the value of χ or to diminish it. For convenience I shall suppose that the errors produced are always errors of excess, since it is only the numerical value of the error which it is necessary to examine.

1. Let us suppose β and r to have been truly adjusted, and a very small error to occur in α. Let this error be represented by α', and let ε represent the resulting error in χ. We then have:

$$\chi + \varepsilon = \frac{1}{2} r^3 \frac{\sin (\alpha + \alpha')}{\sin (\beta - \alpha - \alpha')} \text{ and eliminating } \chi \text{ by Eq. (2),}$$

$$\varepsilon = \frac{1}{2} r^3 \left(\frac{\sin (\alpha + \alpha')}{\sin (\beta - \alpha - \alpha')} - \frac{\sin \alpha}{\sin (\beta - \alpha)} \right)$$

But if α' is very small, we may substitute for the quantity in the parenthesis the value $\alpha' \frac{du}{d\alpha}$, in which u represents $\frac{\sin \alpha}{\sin (\beta - \alpha)}$.* We thus obtain

* For let h be an increment of the variable in $f(\chi)$. Then $\frac{f(\chi + h) - f\chi}{h} = f'\chi + e$, in which $f'\chi$ represents $\frac{du}{d\chi}$. But h and e vanish together. Hence, for very small values of h we have $f(\chi + h) - f\chi = hf'\chi + he$, in which h and e are of the same order of magnitude, and their product is insignificant in comparison with $hf'\chi$. We may therefore write $f(\chi + h) - f\chi = hf'\chi$.

$$\varepsilon = \frac{1}{2} r^3 \frac{\sin \beta}{\sin^2 (\beta - \alpha)} \alpha'$$

and combining with Eq. (2),

$$\varepsilon = \frac{\chi \sin \beta \alpha'}{\sin \alpha \sin (\beta - \alpha)}$$

This is least when $\beta = 180^\circ$ (since we cannot have $\beta = 0$), and when r is so taken that $\alpha = 90^\circ$. Therefore, if we regard errors in α alone, the best position for the deflector is in the magnetic meridian at such a distance that the suspended magnet shall be in the magnetic prime-vertical.

2. Let us suppose a slight error to be made in β alone. We shall obtain by an exactly similar process—

$$\varepsilon' = \frac{\chi \cos (\beta - \alpha) \beta'}{\sin (\beta - \alpha)}$$

in which β' is the error in β, and ε' the resulting error in χ. Hence, if we consider the effects of errors in β alone, the apparatus must be so adjusted that the magnets shall be perpendicular to each other, in order to obtain the least resulting error.

3. Let us suppose a slight error to have been made in r alone. We obtain as before,—

$$\varepsilon'' = \frac{3 \chi r'}{r}$$

in which r' is the error in r, and ε'' the resulting error in χ. Hence, if we consider the effect of errors in r alone, the value of r should be taken as great as possible.

Let us now suppose that the errors α', β', r' occur simultaneously. We shall then have

$$(\varepsilon) = \chi \left(\frac{\sin \beta}{\sin \alpha \sin (\beta - \alpha)} \alpha' + \frac{\cos (\beta - \alpha)}{\sin (\beta - \alpha)} \beta' + \frac{3 r'}{r} \right)$$

in which (ε) represents the resulting error in χ.

It is to be noticed that any two of these errors may occur with the same or different signs; but we suppose that they always occur so as to augment the value of (ε). Under this supposition the equation gives us the greatest possible error for given values of α, β, r, α', β', r'. For the sake of clearness I shall call this the *augmented error*. From this equation we may eliminate r by means of Eq. (2). Then supposing the errors α', β', r' to be numerically equal, and representing the co-efficient of augmented error $\left(\frac{(\varepsilon)}{\alpha'} \right)$ by E, we obtain

$$\mathrm{E} = \chi \left(\frac{\sin \beta}{\sin \alpha \sin (\beta - \alpha)} + \frac{\cos (\beta - \alpha)}{\sin (\beta - \alpha)} + 3 \sqrt[3]{\frac{\sin \alpha}{2 \chi \sin (\beta - \alpha)}} \right)$$

We have now to determine the positions of the magnets which correspond to the smallest value of E. Without respect to the values of α and β, it is evident that we must have $\beta - \alpha = 90°$, and our equation becomes

$$E = \chi \left(\cot \alpha + 3 \sqrt[3]{\frac{\sin \alpha}{2\chi}} \right) \qquad (3)$$

Differentiating with respect to E and α, and placing first derivative of E equal to zero, we obtain

$$\sqrt{\cos^3 \alpha} - \sqrt{\cos^7 \alpha} = \sqrt{2\chi} \qquad (4)$$

The roots of this equation will give the values of α corresponding to all maximum and minimum values of E, but we only need to consider those values of α which are included between 0 and 90°, since at 90° cot α changes sign, and in accordance with our assumed conditions, the two terms in the value of E must have the same sign.

Differentiating Eq. (4) with reference to 2χ and α and placing the first derivative equal to zero, we obtain

$$7 \sin^2 \alpha = 4$$

which gives for the value of α corresponding to the greatest possible value of χ consistent with Eq. (4), $\alpha = 49° 06' 24''$, and this in Eq. (4) gives $\chi = 0.04580$. For all greater values of χ, E will decrease as α increases from 0 to 90°, and the least value of E for all such values of χ corresponds to $\alpha = 90°$. A further discussion of Eq. (4), which is too long to be given here, shows that for every value of χ less than the limit given there are generally two values of α less than 90° which satisfy the equation. The smaller corresponds to a minimum and the greater to a maximum value of E.

From this discussion it appears that for all values of χ greater than 0.04580, the best position for the deflector is in the magnetic meridian, and at such a distance that the suspended magnet shall rest in the magnetic prime-vertical. For a value of χ less than the above, the deflector should be so placed as to give an angle of deflection equal to the least value of α given by Eq. (4). However, it is to be remarked that although such a value of α gives a minimum error, it does not always give the smallest error. For if we make $\alpha = 90°$ in the second member of Eq. (3), place the result equal to the second member of that equation, and combine the resulting equation with Eq. (4), we obtain

$$\cot \alpha \sqrt[3]{\cos^3 \alpha - 2 \cos^5 \alpha + \cos^7 \alpha} + 3 \sqrt[3]{\sin \alpha} = 3$$

which is satisfied by $\alpha = 31° 24'$. Hence, for all values of α greater than this, we have a greater error than we have for $\alpha = 90°$. But the difference in the errors will not be great, while the difference in r is decidedly in favor of the minimum value.

Up to the present time the magnets employed have been generally of such size as to

make χ, for ordinary values of φ and θ, much greater than the limit given. The methods followed have been that of Gauss, in which the deflector is at right-angles to the magnetic meridian; and that of Lamont, in which the magnets are at right-angles to each other.* Of the two methods the latter is the more accurate, as is shown by the above discussion. But it has been found necessary to make a small and r large in order to diminish the effect of errors arising from unequal distribution, etc. The method of Lamont has the advantage of dispensing with the correction for torsion, although I doubt whether there is much increase of accuracy on this account. Perhaps as much error arises from torsional changes due to atmospheric disturbances as from errors in determinations of the co-efficient. The formula is more nearly rigorous in the method of Lamont, and the distance may safely be made less than in the first method. The method of Gauss appears to me to have but one advantage: it requires no correction for induction due to the position of the deflector.

With regard to the modification of the method of Lamont which I have indicated above for the larger values of χ, it is to be said that the co efficient of augmented error is least for this arrangement. Moreover, the inductive effect of the earth is the same during the experiments of oscillation and those of deflection, so that the resulting determination of $\varphi \cos \theta$ is independent of induction; which is not the case in the other methods. On the other hand, r is comparatively small, so that errors from unequal distribution will have more effect; and the experiments of Lamont seem to indicate uncertainty when either magnet is placed in the magnetic prime-vertical.

Eq. (3) shows that the co-efficient of augmented error diminishes with χ. This quantity may be decreased by reducing the amount of magnetism in the magnet or by diminishing its dimensions. The latter method is evidently the better, for in this case r will be relatively greater in comparison with the lengths of the magnets. With very small magnets, the danger of accidental displacement, by air-currents, etc., will be greater, and the necessity for care in observation will be increased. On the other hand, such magnets are steadier and indicate slight changes of intensity more readily. Mr. Schott has used deflectors as small as 1.25 inches. I am led to believe, from the above discussion, that the best results can be obtained by using very small magnets, highly saturated, with angles of deflection much larger than those heretofore employed.

* Eq. (1) is applicable to both of these methods. For the first we have $\beta = 90°$ and $\frac{m}{\varphi \cos \theta} = \frac{1}{2} r^3 \tan \alpha \left(1 - \frac{P}{r^2}\right)$. For the second we have $\beta - \alpha = 90$ and $\frac{m}{\varphi \cos \theta} = \frac{1}{2} r^3 \sin \alpha \left(1 - \frac{P}{r^2}\right)$. The second form is given in my paper before referred to.

It may be thought that the gain in accuracy obtained by taking the best theoretical positions is too small to be of consequence, but this is certainly not the case. Taking an example given by Mr. Schott where $\alpha = 6° 32'.7$, I find that the co-efficient of augmented error is more than twice as great for this angle as it is for the theoretical one.

Of course, this discussion cannot be regarded as deciding the question of position. There are several causes of error which can scarcely be analyzed; so that a series of careful experiments is required. It was as a basis for such experiments that these notes were originally prepared. I publish them now because I see no immediate prospect of completing the original plan.

The annexed table gives the theoretical distances for the deflector for values of χ less than 0.04580. The fourth column gives (α) the angle of deflection for the distance $r = 0.5$. In practice the deflector may be placed at 0.5, the value of (α) determined, and the corresponding value of r taken from the table; or a value of χ computed from approximate values of m and $\varphi \cos \theta$, may be used as an argument.

TABLE OF DEFLECTION DISTANCES.

α	χ	r	(α)	α	χ	r	(α)
		ft.	′ ″	′		ft.	° ′ ″
11	0.00059	0.1830	0 32 11	31	0.02218	0.4416	20 46 50
12	0.00088	0.2038	0 48 24	32	0.02404	0.4528	22 37 20
13	0.00119	0.2195	1 05 28	33	0.02596	0.4568	24 32 10
14	0.00156	0.2345	0 25 49	34	0.02786	0.4636	26 28 00
15	0.00202	0.2499	0 51 08	35	0.02975	0.4698	28 25 10
16	0.00257	0.2652	2 24 21	36	0.03160	0.4755	30 22 20
17	0.00320	0.2796	0 55 49	37	0.03340	0.4806	32 18 10
18	0.00392	0.2937	3 35 29	38	0.03515	0.4852	34 13 20
19	0.00475	0.3079	4 21 31	39	0.03681	0.4891	36 04 30
20	0.00569	0.3215	5 13 10	40	0.03837	0.4924	37 52 30
21	0.00672	0.3346	6 10 10	41	0.03982	0.4951	39 34 20
22	0.00785	0.3473	7 12 40	42	0.04114	0.4973	41 10 00
23	0.00909	0.3597	8 21 30	43	0.04231	0.4988	42 36 30
24	0.01043	0.3715	9 36 20	44	0.04334	0.4997	43 53 50
25	0.01188	0.3831	10 57 30	45	0.04420	0.5000	45 00 00
26	0.01341	0.3970	12 23 10	46	0.04488	0.4997	45 53 40
27	0.01503	0.4045	13 54 40	47	0.04538	0.4988	46 33 30
28	0.01672	0.4145	15 31 00	48	0.04569	0.4973	46 58 30
29	0.01849	0.4241	17 12 10	49	0.04581	0.4951	47 07 40
30	0.02030	0.4330	18 57 10	49° 06′ 24″	0.04580	0.4949	47 07 20

NOTES

ON

DISTRIBUTION OF MAGNETISM.

READ BEFORE THE ESSAYONS CLUB OF THE CORPS OF ENGINEERS,

MAY 22, 1877;

FROM

CAPT. C. W. RAYMOND,
CORPS OF ENGINEERS.

NO. XLIV. PRINTED PAPERS.

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NOTES ON DISTRIBUTION OF MAGNETISM.

A paper read before the "ESSAYONS CLUB" of the Corps of Engineers, on May 22, 1877, from Capt. C. W. Raymond, Corps of Engineers.

In the preceding discussion * it has been supposed that the magnetism in each magnet is symmetrically distributed with reference to the centre. This is not the case with large magnets, but with respect to the small ones used in our magnetometers, which can be made much more homogeneous, it is probably very nearly true where they have been carefully magnetized. The determination of the law of the magnetic distribution is not only a matter of general scientific interest, but it is of practical importance in connection with the theory of magnetic measurements.

The irregularities of distribution in large magnets have recently received much attention from several skillful experimenters. The results from small magnets, as far as I am acquainted with them, do not seem to be satisfactory. The following method of investigation seems to me to promise valuable results. I am not aware that it has been proposed before.

If a horizontal suspended magnet be deflected by a fixed one, their axes being perpendicular to each other, we have for the equation of equilibrium (as in the preceding note)

$$\int\int \frac{(r-u)\,u' f(u) f(u')\,du\,du'}{[(r-u)^2+u'^2]^{\frac{3}{2}}} = \varphi \cos\theta \sin\alpha \int u' f(u')\,du' = \int\int \frac{1}{r^2}\Big[u' + \frac{2}{r}u\,u' + \frac{3}{2r^2}(2u^2u' - u'^3) + \frac{2}{r^3}(2u^3u' - 3u\,u'^3) + \frac{5}{r^4}\Big(u^4u' - 3u^2u'^3 + \frac{3}{8}u'^5\Big) + \frac{6}{r^5}\Big(u^5u' - 5u^3u'^3 + \frac{15}{8}u\,u'^5\Big) + - -\Big] f(u) f(u')\,du\,du'$$

* Printed Paper, No. XLIII, 1877—Essayons Club.

But $\int f'(u)\,du = 0$, $\int f(u')\,du' = 0$, $\int u^2 f(u)\,du = 0$, $\int u'^2 f(u')\,du' = 0$,

$\int u^4 f'(u)\,du = 0$. Hence we have $\frac{1}{r^3 \sin\alpha} + \frac{1}{r^5 \sin\alpha}\left(2\frac{m_3}{m} - 3\frac{m'_3}{m'}\right) +$

$\frac{1}{r^7 \sin\alpha}\left(3\frac{m_5}{m} + 5.625\frac{m'_5}{m'} - 15\frac{m_3}{m}\cdot\frac{m'_3}{m'}\right) = \frac{\varphi\cos\theta}{2m}$ in which $m = \int u f(u)\,du$

$m' = \int u' f(u')\,du'$ $\qquad m_3 = \int u^3 f(u)\,du$ $\qquad m'_3 = \int u'^3 f(u')\,du'$

$m_5 = \int u^5 f'(u)\,du$ $\qquad m'_5 = \int u'^5 f(u')\,du$

Now let us write $k u^n$ for $f(u)$, in which k represents a constant which has a different value for each magnet and depends upon the degree of magnetization, and n represents a positive number to be determined. Representing the semi-lengths of the deflecting and suspended magnets by a and a' respectively, integrating the above expressions between the limits $+a$ and $-a$, $+a'$ and $-a'$, and substituting above, we obtain

$$\frac{1}{r^3 \sin\alpha} + \frac{1}{r^5 \sin\alpha}\left[\frac{n+2}{n+4}\left(2\frac{a^{n+4} \pm a^{n+4}}{a^{n+2} \pm a^{n+2}} - 3\frac{a'^{n+4} \pm a'^{n+4}}{a'^{n+2} \pm a'^{n+2}}\right)\right]$$

$$+ \frac{1}{r^7 \sin\alpha}\left[\frac{n+2}{n+6}\left(3\frac{a^{n+6} \pm a^{n+6}}{a^{n+2} \pm a^{n+2}} + 5.625\frac{a^{n+6} \pm a^{n+6}}{a^{n+2} \pm a^{n+2}}\right)\right.$$

$$\left. - 15\left(\frac{n+2}{n+4}\right)^2 \frac{a^{n+4} \pm a^{n+4}}{a^{n+2} \pm a^{n+2}}\cdot\frac{a'^{n+4} \pm a'^{n+4}}{a'^{n+2} \pm a'^{n+2}}\right] = \frac{\varphi\cos\theta}{2m}$$

The upper sign corresponds to an odd value of n, and the lower to an even value.

But if n is an even number, whether whole or fractional, all the terms of the first member of the above equation vanish, except the first, and we have $\frac{m}{\varphi\cos\theta} = \frac{1}{2} r^3 \sin\alpha$; hence, the sine of the angle of deflection varies inversely as the cube of the distance. But the variation from this relation, in the ordinary experiments of deflection is too marked to be accounted for by reference to errors of observation; hence I conclude that:

If the distribution of magnetism in a small cylindrical magnet is symmetrical with reference to the magnetic centre, and if the quantity of magnetism in a section at any point can be expressed by any power of the distance from that centre, *the exponent of that power must be an odd number.*

Coulomb and Lambert concluded from their experiments that the quantity varies with the first power of the distance. Hanstein, on the other hand, thought it varied with the square of the distance. Apparently the latter cannot be right.

The second member of the above equation is constant for a given time and place; hence, if we make a second deflection with a new distance r' and a new angle α', we shall obtain a precisely similar equation except that r becomes r' and α, α'. Placing the first member of this second equation equal to the first member of the preceding one, and reducing, we obtain

$$An^3 + Bn^2 + Cn + D = 0$$

in which A, B, C and D are quantities which depend only upon α, α', r, r', α and α', and are therefore known. In order to determine the value of n, the equation may be written

$$n = -\frac{B}{2A} + \sqrt{\frac{B^2}{4A^2} - \frac{C}{A} - \frac{D}{An}}$$

which approximates rapidly.

The values of the constants are given by the following formulas:

$$A = \triangle + \triangle' + \triangle'' - \triangle'''$$
$$B = 14\triangle + 12\triangle' + 10\triangle'' - 10\triangle'''$$
$$C = 64\triangle + 44\triangle' + 32\triangle'' - 28\triangle'''$$
$$D = 96\triangle + 48\triangle' + 32\triangle'' - 24\triangle'''$$

in which

$$\angle = \frac{1}{r^3 \sin\alpha} - \frac{1}{r'^3 \sin\alpha'}$$

$$\angle' = \left(\frac{1}{r^5 \sin\alpha} - \frac{1}{r'^5 \sin\alpha'}\right)(2\alpha^2 - 3\alpha'^2)$$

$$\triangle'' = \left(\frac{1}{r^7 \sin\alpha} - \frac{1}{r'^7 \sin\alpha'}\right)(3\alpha^4 + 5.625\alpha'^4)$$

$$\triangle''' = 15\left(\frac{1}{r^7 \sin\alpha} - \frac{1}{r'^7 \sin\alpha'}\right)\alpha^2\alpha'^2$$

Coulomb investigated the distribution of free magnetism by swinging a small magnet opposite the different points of a large one, and timing its oscillations. The relative force was thus obtained. This method is open to the objections that the distribution is disturbed unsymmetrically by the reciprocal action of the magnets on each other, and that the force measured is not that exerted by a single layer, but is more or less intensified by the rest of the stationary magnet. The electro-dynamic method of Lenz and Jacobi, which has been admirably employed by Mayer and Rowland in this country, and by Jamin and others in Europe (although always, I believe, with long magnets), is apparently open to the same objection in the case of small magnets; and so is the method given by Snow Harris, which consists in measuring the force necessary to pull a piece of soft iron from a magnetic bar.

In the method I have indicated, the formula may be regarded as rigorous, for no terms with smaller denominators than the ninth power of the distance have been omitted. The value of r being large compared with the lengths of the magnets, the effect of their reciprocal action on the distribution will be scarcely, if at all appreciable, and as far as the suspended magnet is concerned, the disturbance will be practically symmetrical with respect to its centre, if we take into consideration the earth's action. Another advantage of this method is that it is independent of variations in the degree of saturation; for the magnetic constant k disappears from the equation.

The method consists practically in the measurement of the variations of the sines of the angles of deflection from proportionality to the inverse cube of the distance; and as these variations are small, it is a question, only to be decided by careful experiment, whether they can be measured with sufficient accuracy to give satisfactory results. However, it is to be remarked that by proper apparatus it is possible to carry the measurements to a much higher degree of accuracy than can be obtained with ordinary magnetometers.

It is evident that the conditions of the experiment ought to be very different from those which obtain with the usual magnetic instruments. In these the magnets are always so proportioned as to reduce the variations which we wish to measure as much as possible. Our formulas show that the distances r and r', and also the lengths of the magnets, should differ as much as possible; and contrary to the usual practice, the short magnet should be the deflector.

Another element of error consists in the fact that we assume the earth's magnetic intensity to be constant during the experiments, while it is, in reality, continually varying. To avoid this difficulty, each set of deflections should be made rapidly, and the hour should be selected when the force is steadiest. With a second (differential) apparatus, changes may be watched during the experiments, and measurements may thus be corrected or rejected.

Should the method be found to admit of sufficient accuracy, it may be possible to detect the difference in distribution in the two magnets due to reciprocal action at short distances. For this purpose, we have only to write $f'(u') = k\,u'^{n'}$ in our formulas, and the values of the two unknown quantities n and n' may be determined when we have obtained from experiments the data for two conditional equations. In all probability such a determination is too refined for practice.

Finally, it must be remembered that we have assumed the law of distribution to be expressed by $f'(u) = k\,u^n$. This may not represent it with sufficient accuracy, although it would seem that the approximation ought to be close for small magnets. But we are

not limited to this value. We may, for instance, write $f(u) = k n^u$ (which conforms to Biot's determinations from Coulomb's experiments), and deducing our final formula in conformity with this supposition, we can proceed to determine n as before. The relation given by the equation of equilibrium is so complicated that probably the form of the function can only be determined from it by trial.

USEFUL TABLES

FOR

FINDING SPECIFIC GRAVITY.

READ BEFORE THE ESSAYONS CLUB OF THE CORPS OF ENGINEERS,

APRIL 14, 1879;

BY

BVT. LIEUT. COL. A. HEGER,
SURGEON, U. S. ARMY.

NO. XLV. PRINTED PAPERS.

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USEFUL TABLES FOR FINDING SPECIFIC GRAVITIES.

A paper read before the "ESSAYONS CLUB" of the Corps of Engineers, on April 14th, 1879, by Surg. A. Heger, U. S. Army.

While making determinations of specific gravity and of the volume of the contents of vessels, the annexed tables were constructed. As they may be of service in similar investigations, they are hereby presented.

The most important data in such investigations are the volume or density of pure water and of mercury.

The expansion of pure water has only been ascertained to a limited extent, as may be seen from a comparison of the results of different investigations given in Table I. These differences are partially due to errors in instruments and to the methods pursued in the investigations; partly, as Prof. Miller pointed out, to errors in the constants used in the reduction of the observations; partly, as Rosetti asserts, to the presence of air remaining in the water even after prolonged boiling. This presence of air has considerable influence on the expansion of water, especially at higher temperatures. Experiments have also been made (Annal. de Chem. et Phys., 1869) which show, that the presence of more or less air or of other gases has a decided influence in lowering the freezing point of water.

Table I contains:

1st, The volume of water according to *Hällstroem*; Poggendorf Annalen I, 1824, p. 168.
2nd, " " " " " *Stampfer*; Poggendorf Annalen XXI, 1831, p. 176.
3rd, " " " " " *Depretz*; Annal. de Chem. & Phys. LXX, 1839, [p. 23.
4th, " " " " " *Kopp*; Poggendorf Annalen LXXII, 1847, p. 44.
5th, " " " " " *Pierre*; copied from Rosetti's Table, l. c.
6th, " " " " " *Hagen*; Akademie der Wissenschaft, Berlin, 1855, [Mathem. Theil, p. 6.

7th. The volume of water according to *Plücker & Geissler*; Poggendorf Annalen, Vol. [86, p. 451; Phil. Trans., London, 1856.

8th, " " " " " *Miller*; adopted by him, Phil. Trans., London, [1856.

9th, " " " " " *Matthiessen*; Phil. Trans. Royal Society, London, [1866, Vol. 156, p. 231.

10th, " " " " " *Weider*; copied from Rosetti's Table, l. c.

11th, " " " " " *Rosetti, 1st series*; Annal. Chem. & Phys., X, [1867, p. 471.

12th, " " " " " *Rosetti, 2nd series*; Annal. Chim. & Phys., XVII, [1869.

Hällstroem used a hollow glass globe slightly heavier than water as a plunger, and determined the density of water at different temperatures. The cubical dilatation of this plunger he assumed from the linear expansion of a rod made from the same run of glass.

Stampfer determined the density of water by means of a thin hollow cylinder of brass filled with air at 15° C., and then closed air-tight, the volume of which was determined by measurements with callipers (pressure levers) at different temperatures in the air before experimenting.

Depretz's determinations were made for volume, on the principle of a water thermometer compared with a standard thermometer; volume of bulb, graduation and expansion of glass having been determined before experimenting. After each determination the freezing point of the standard was verified.

Pouillet recalculates these observations, and gives somewhat different values for Depretz's observations in his Mémoire sur la Densité de l'Alcool, 1859, page 8, which are embodied in the following table:

Temp. C.	Density. Depretz.	Density. Pouillet.	Temp. C.	Density. Depretz.	Density. Pouillet.	Temp. C.	Density. Depretz.	Density. Pouillet.
°			°			°		
0	0.999 862	0.999 873	6	0.999 977	0.999 969	12	0.999 636	0.999 524
1	924	927	7	919	929	13	435	408
2	963	966	8	908	878	14	338	277
3	999	999	9	901	812	15	125	133
4	1.000 000	1.000 000	10	831	729	16	0.998 988	0.998 973
5	0.999 999	0.999 999	11	730	637	17	893	793

Kopp's determinations were made in a manner similar to Depretz with a water thermometer.

Prof. Miller takes the observations of Depretz, Kopp and Pierre, corrects these by constants selected from other investigators, and from the mean of the so reconstructed

tables he deduces a formula, by which he calculates his table of volume of water.

Matthiessen determined the density of water by plungers made in the shape of cones cut from glass rods, the linear expansion of which latter he had carefully determined, assuming the cubical dilatation of these cones equal to three times the linear expansion of the rods. The water was simply distilled in a copper still, placed into the vessel and boiled half an hour with the plunger in it, and thus experimented with. The temperature of the water was measured by a standard thermometer, and its indications corrected by another thermometer placed half way up the exposed stem of the former. Barometer and thermometer in air, except in a few experiments, were only read once a day, and no observations taken of the vapour of water present. Matthiessen believes Kopp's coefficient too low and Depretz's nearly correct. He believes that impurities in water have only an imperceptible influence on expansion of water.

Rosetti used Regnault's apparatus: i. e., a flask, the capacity and cubical expansion of which was known, and in the determination of the weight of its contents was balanced by a similar flask having the same weight and displacement, so that no correction for the same was required. His experiments differed not only from those of other observers, but his first series of determinations differed also from those of his second series, which led him to the conclusions about differences in the purity of waters as stated above. He believes, that for low temperatures the sixth decimal is uncertain, and for higher temperatures the fifth to be the limit. After comparing his own experiments with those of the various investigators, which preceded him, he adopted a table of volume and density of water, which is given in Table II, and copied from Annal. Chem. et Phys., 4th series, Tom. XVII, 1869, having its unit volume and density at 0° C.

Table III gives the volume of water for each degree Centigrade from 0° C. to 40° C. and its logarithm. Its unit volume is taken at 4° C. It is copied from Rosetti l. c.

Table IV. Is the same table as the preceding one, only in degrees of Fahrenheit, from 32° F. to 104° F. It was constructed by myself, being calculated by Rosetti's 1st formula, and made to agree with Table III by interpolation.

The maximum density of water has been assumed at different temperatures by different investigators:

Depretz found it by the water thermometer =4.007° C; by other methods, 3.987° C. Mean, 3.997° C. *Kopp* gives it at 4.05° C., *Pierre* at 3.86° C., *Hagen* at 3.87° C., *Matthiessen* at 4° C., *Rosetti*, 1st experiment, at 4.07° C., 2nd experiment at 4.04° C., *Playfair & Joule* at 3.945° C.

In consequence of the temperature of the maximum density of water being above 0° C. there is a temperature, at which the volume of water is equal to that of water at

0° C. This temperature is given by Kopp as 8.24° C., by Rosetti as 8.46° C.

Different investigators sought for empirical formulas to represent the volume of water at different temperatures.

Kopp gave four formulas, one for volume of water from 0° to 25°; a second from 25° to 50°; a third from 50° to 75°; and the 4th from 75° to 100° C., viz:

log. - - - - - - - - - ($\bar{5}.785\,65$) ($\bar{6}.887\,52$) ($\bar{8}.572\,17$)
From 0° to 25° C.; $V\,t = 1 - 0.000\,061\,045t + 0.000\,007\,718\,3t^2 - 0.000\,000\,037\,34t^3$

log. - - - - - - - - - ($\bar{5}.815\,67$) ($\bar{6}.889\,79$) ($\bar{8}.549\,11$)
" 25° to 50° C.; $V\,t = 1 - 0.000\,065\,415t + 0.000\,007\,758\,7t^2 - 0.000\,000\,035\,48t^3$

log. - - - - - - - - - ($\bar{5}.772\,03$) ($\bar{6}.503\,10$) ($\bar{9}.862\,42$)
" 50° to 75° C.; $V\,t = 1 - 0.000\,059\,16t + 0.000\,003\,184\,9t^2 - 0.000\,000\,007\,284\,8t^3$

log. - - - - - - - - - ($\bar{5}.936\,76$) ($\bar{6}.503\,68$) ($\bar{9}.388\,93$)
" 75° to 100° C.; $V\,t = 1 - 0.000\,086\,45t + 0.000\,003\,189t^2 - 0.000\,000\,002\,448\,7t^3$

Matthiessen gave two formulas, one between temperatures 4° to 32° C., the second from 32° to 100° C.

From 4° to 32°; $V\,t = 1 - 0.000\,002\,53(t-4) + 0.000\,000\,838\,9(t-4)^2 - 0.000\,000\,071\,73(t-4)^3$
" 32° to 100°; $V\,t = 0.999\,695 + 0.000\,005\,472\,4t^2 - 0.000\,000\,011\,26t^3$.

Miller's formula, representing the means of Kopp's, Depretz's and Pierre's values, corrected by himself, as stated above, between 4° to 25° C., is, viz:

$$V\,t = 32.72(t-3.945)^2 - 0.215(t-3.945)^3.$$

This formula gives the logarithm of the volume; the integer of the number found being regarded as the seventh decimal of the logarithm sought for.

Rosetti deduces two formulas. The first, he states, differs less than $\pm 0.000\,03$ from true value; the second only 0.000 05.

1*st Formula:*

log. - ($\bar{6}.923\,239\,3$) ($\bar{7}.578\,296\,5$) ($\bar{8}.350\,885\,4$)
$V\,t = 1 + 0.000\,008\,379\,91(t-4)^2 - 0.000\,000\,378\,702(t-4)^{2.6} + 0.000\,000\,022\,432\,9(t-4)^3$

2*nd Formula:*

log. - ($\bar{6}.907\,814\,3$) ($\bar{7}.464\,236\,1$) ($\bar{8}.660\,656\,8$)
$V\,t = 1 + 0.000\,008\,087\,5(t-4)^2 - 0.000\,000\,082\,146(t-4)^{2.6} + 0.000\,000\,045\,778(t-4)^{3.2}$.

For Fahrenheit degrees, the first formula becomes

log. - - ($\bar{6}.412\,694\,1$) ($\bar{8}.914\,587\,1$)
$V\,t' = 1 + 0.000\,002\,586\,4(t'-39.2)^2 - 0.000\,000\,082\,146(t'-3.92)^{2.6} +$
($\bar{9}.585\,067\,6$)
$+ 0.000\,000\,003\,846\,32(t'-3.92)^3$

Table V gives volume of mercury for each degree, from 0° to 40° C., and its logarithm. It was constructed by Regnault's formula $V\,t = 1 + at + bt^2$, where

$\log. a = \bar{4}.252\,869\,2 = \log. 0.000\,179\,006\,66.$
$\log. b = \bar{8}.401\,944\,1 = \log. 0.000\,000\,025\,231\,56.$

Vide Jamin Cours de Phys., 1859, II, p. 26.

This formula for degrees Fahrenheit becomes

$$[\log.] - (\bar{5}.997\,596\,7) \qquad (\bar{9}.891\,399\,1)$$
$$V\,t' = 1 + 0.000\,099\,448\,15(t-32) + 0.000\,000\,007\,787\,52(t-32)^2.$$
$$[\log.] - - (1.133\,409\,6)$$

The density of mercury at 0° C. to water at maximum density is $= 13.595\,95$. Jamin l. c.

Table VI was calculated by the latter formula, and gives the volume of mercury for each degree Fahrenheit, from 32° to 100°, and also its logarithm.

WEIGHT IN VACUO.

In investigations for specific gravity and for volume by weight, i. e., in all investigations, where the balance is used (except between bodies of the same density or in weighing in vacuo), a correction is required for loss of weight in air (or in the medium in which the weighing is effected). It is necessary therefore to ascertain the density of the air at the time of weighing. For this purpose the weight of a given volume of air, or its density, under certain conditions, usually under pressure of 760 mm. at 0° C. of dry atmospheric air, has been determined. From this, by means of constants, the density at the time of experiment is found by calculation.

The determination by *Regnault* of the weight of a litre of dry air $= 1.293187$ grm. at Paris in latitude 45° 50′ 14″, 60 metres above level of the sea, at 0° C., and under pressure of 760 mm. (Mem. de l'Institute, XXI, p. 157), forms the basis from which all other values are deduced. This value was corrected by E. Ritter (Mem. de la Societé Phys. de Geneva, XIII, p. 361) for an error in computation, and its value found = 1.293 222 7. From this last value, by applying the formula for change of gravity for latitude and height above sea-level, the weight of a litre of air at level of the sea in latitude 45° at 0° C. and 760 mm. pressure was deduced. This is assumed by *Prof. Miller*, introducing a correction for carbonic anhydride, as $= 1.293\,069\,3$ grm.; by the Standard Commission at Berlin as 1.293 030 grm.. *Prof. Miller* uses *Baily's* and *Poisson's* formulas and gives the weight of a litre of air at 0° C., and under 760 mm. pressure at any station $= 1.293\,063^{\text{grm.}} \left(1 - 1.32\frac{\zeta}{R}\right)(1 - 0.0025659 \cos. 2\lambda)$ where ζ = height of station above sea level in metres, λ = latitude of station, and R = mean radius of earth = 636 619 8 metres. *Jamin* in Cours de Phys., II, p. 179, gives weight of a c. c. metre of

such air $=0.001\,292\,673\,\frac{R^2}{(R+\zeta)^2}\,(1-0.002\,837\cos.\,2\lambda)$. This formula requires correction in its first factor; in both formulas the value of R is doubtful as well as the coefficient for cos. 2λ.

The Berlin Standard Commission publishes a table of weight of a litre of air under the above conditions, which is represented in the following table:

TABLE OF WEIGHT OF A LITRE OF DRY AIR AT 0° C. AND 760 mm. PRESSURE.

Lat.	Height in metres above sea level.					
	0	50	100	150	200	250
40	1.29 245	1.29 244	1.29 243	1.29 241	1.29 240	1.29 239
41	257	255	254	253	251	250
42	268	267	266	264	263	262
43	280	278	277	276	274	273
44	291	290	289	287	286	285
45	303	302	300	299	298	296
46	315	313	312	311	309	308
47	326	325	324	322	321	320
48	338	336	335	334	332	331
49	349	348	346	345	344	342
50	361	359	358	357	355	354
51	372	371	369	368	367	365
52	383	382	380	379	378	377
53	394	393	392	390	389	388
54	405	404	403	401	400	399
55	416	415	414	412	411	410

As the force of gravity does vary not only with latitude or elevation, but is also subject to local changes in the same latitude and elevation, all these theoretical values are only approximations, and if the utmost accuracy is required, the local value of "g'" has to be ascertained and compared with the "g'" of the place, where the weight of the litre of air was determined.

Having ascertained the weight of a litre of dry air at 0° C. and 760 mm. pressure at the place of the experiments ($\frac{1}{1000}$ part of which is the theoretical density (a) to water at its maximum density), we find the density of the air at the time of experiment $=(a')$, by the following formula: $a'=a.\frac{h-0.378f}{(1+0.003\,665t)760}$ where "h" is the barometric pressure in millimetres, reduced to 0° C.; "f" the elastic force of vapor of water contained in the air in milimetres, and "t" the temperature of the air in degrees Centigrade. For barometric pressure and force of vapor in English inches, and temperature in degrees Fahrenheit, the formula becomes: $a'=a.\frac{h'-0.378f'}{[1+0.002\,036\,11\cdot\cdot(t'-32)]29.9215}$

This formula can also be placed under the following form :

$$a' = a\frac{h'}{[1+0.002\,036\,11\cdot\cdot(t-32)]29.9215} - a\frac{0.378f'}{[1+0.002\,036\,11\cdot\cdot(t-32)]29.9215}$$

and a table for the positive term, as well as an auxiliary table for negative term, can easily be formed, giving on inspection, with very slight interpolation, the two terms, the sum of which gives value of a'.

The barometric observation requires the following corrections: 1st, for index error, if the scale is incorrectly placed; 2nd, for capillary depression (both these corrections, being constant, can be made by shifting the scale); 3rd, for temperature; 4th, for depression due to tension of mercurial vapor.

Table VII gives the tension of mercurial vapor for each degree C., from 0° C. to 40° C., according to Regnault.

Table VIII gives the same for each degree Fahrenheit, from 32° F. to 104° F., from same data.

Table IX gives the factor ζ, to be multiplied with the observed height of mercurial column, in order to obtain the correction to be applied to the observed height, with + or − sign, according to "t" being below or above 0° C. This correction can be used with any barometer, the scale of which is of brass and correct at 0° C., and "t" given in Centigrade degrees. This table was calculated by formula $\zeta = \frac{Et - 0.000\,018\,76t}{1+Et}$ where "Et" indicates the dilatation of mercury as taken from Table V, and "t" the temperature indicated by attached thermometer in degrees C.

Table X gives the factor ζ', to be used in a similar manner, with barometer having brass scales, the latter of which is normal at 62° F., and t' measured by Fahrenheit thermometer. It was calculated by means of formula $\zeta' = \frac{Et' - 0.000\,010\,422\,1(t'-62)}{1+Et'}$ where Et' is the expansion of mercury taken from Table VI, and t' the indications of the attached thermometer in degrees Fahrenheit.

Table XI gives a compact table for correcting barometrical readings and for their reduction to freezing point of English barometers with brass scales, between 32° F. and 98° F., and from 28 to 30 inches. This table is entered with argument "t" in the 1st column. The next column gives the tension of mercurial vapor, which is additive. The next three columns gives the correction for reducing to freezing point according to argument H (observed height). This correction, as far as found in this table, is subtractive. The last column gives the difference for 0.1 of an inch. The comma indicates the posi-

tion of the product under the 4th decimal of correction, when the difference given in this column has been multiplied with the fractional part of the inch of H, with its 0.1 as unit (i. e., H = 29.786. Multiply 7,86 with difference of last column). It is evident that this table can be used for H above 30 and below 28 as the differences are given to the 6th decimal. Hence even with a depression of 9 inches below this, i. e. H = 19 inches, the third decimal will be correct. Correction for capillarity is best made by comparison with standard barometers at the same time that the index error is corrected. Tables have been formed giving capillary depression, which are based on the diameter of the tube for boiled and unboiled tubes. But the fact, that the values change with the time of boiling, shows their inaccuracy. Other tables were constructed, having as argument the diameter of tube and versed sine of meniscus. But the difficulty of making these measurements recommends the plan of comparison.

Tables XII and *XIII* give elastic force of vapor of water, according to Regnault, for each degree "*t*," the former from 1° to 40° C., the latter from 0° to 100° F. They are copied from Guyot's Tables, B. 10; and B. 43.

In weighing in air, we balance the substance to be weighed by a weight which has its correct weight in vacuo marked on it. If [P] designates the marked weight, its weight in air will be $P=[P](1-\frac{a'}{\delta}[1+kt])$, where "$\delta$" is the specific gravity of the weight to water at maximum density; a' the density of air, and k the coefficient of the expansion of the weight.

In similar manner, the weight of the substance, to be weighed, being in vacuo $[p]$, in air p, and δ' and k' its specific gravity and coefficient of expansion;

$$p=[p](1-\frac{a'}{\delta'}[1+k't]).$$

As they balance each other, p must be equal to P and therefore

$$[p](1-\frac{a'}{\delta'}[1+k't])=[P]\ (1-\frac{a'}{\delta}[1+kt])$$

which gives

$$[p]=[P]\frac{1-\frac{a'}{\delta}(1+kt)}{1-\frac{a'}{\delta'}(1+k't)}=[P](1-\sigma)\frac{1}{1-\frac{a'}{\delta'}(1+kt)}$$

or approximatively $[p]=[P]\left(1+a'\left[\frac{1+k't}{\delta'}-\frac{1+kt}{\delta}\right]\right)$

In many weighings, as the density of the weight is usually very great, we may sub-

stitute for the true value of σ a mean value, without detriment to the result.

The following table gives the value of σ for some of the principal substances used in weighing, assuming the following data, viz.:

	Mercury.	Glass.	Aluminum.	Brass.	Platinum.	Lead.
Specific Grav.	13.59595	2.7	2.67	8.5	21.5	11.3
Cub. dilatation for 1° C.	See Table V.	0.0000 255	0.0000 7	0.0000 57	0.0000 27	0.0000 855

TABLE OF σ.

	$t°$ C.	$a'=0.0011$.		$a'=0.00115$.		$a'=0.0012$.	
		σ	log. σ.	σ	log. σ	σ	log. σ
For Platinum.	0	0.000 051 1628	$\bar{5}$.708 9542	0.000 053 4884	$\bar{5}$.728 2593	0.000 055 8139	$\bar{5}$.746 7427
	10	1766	.709 0714	5028	3765	8290	.746 8599
	20	1904	.709 1887	5173	4938	8441	.746 9772
	30	2042	.709 3058	5317	6109	8592	.747 0943
For Lead.	0	0.000 097 3452	$\bar{5}$.988 3143	0.000 101 7699	$\bar{4}$.007 6194	0.000 106 1947	$\bar{4}$.026 1028
	10	4386	.988 6865	8572	.007 9916	2857	.026 4750
	20	5116	.989 0563	9439	.008 3614	3763	.026 8448
	30	5948	.989 4268	102 0309	.008 7319	4671	.027 2153
For Brass.	0	0.000 129 412	$\bar{4}$.111 9738	0.000 135 293	$\bar{4}$.131 2789	0.000 141 176	$\bar{4}$.149 7643
	10	485	.112 2213	371	5264	257	.150 0098
	20	559	.112 4686	448	7737	337	.150 2571
	30	633	.112 7158	525	.132 0209	418	.150 5043
For Aluminum.	0	0.000 411 985	$\bar{4}$.614 8814	0.000 430 712	$\bar{4}$.634 1865	0.000 449 438	$\bar{4}$.652 6699
	10	412 273	.615 1853	431 013	4904	449 753	.652 9738
	20	562	4880	315	7941	450 067	.653 2775
	30	850	7925	616	.635 0976	450 382	.653 5810
For Glass.	0	0.000 407 407	$\bar{4}$.610 0289	0.000 425 926	$\bar{4}$.629 3340	0.000 444 444	$\bar{4}$.647 8174
	10	511	1392	426 044	4443	557	.647 9277
	20	614	2495	426 142	5546	670	.648 0380
	30	718	3597	426 250	6648	783	.648 1482
For Mercury.	0	0.000 080 906	$\bar{5}$.907 9831	0.000 084 584	$\bar{5}$.927 2882	0.000 088 262	$\bar{5}$.945 7716
	10	081 051	.908 7609	736	.928 0660	420	.946 5494
	20	197	.909 5395	888	.928 8446	578	.947 3280
	30	343	.910 3189	085 040	.929 6240	738	.948 1074

CAPACITY OF VESSELS.

We take "V" volume of vessel in c. c. metre at 0° C.; "$\varkappa$" its coefficient of cubical expansion for 1° C.

"$\triangle$" the density of the fluid used in the determination at 0° C. to water at maximum density.

"t" the temperature of fluid, vessel and air during the experiment, in degrees Centigrade.

"a'" the weight of a c. c. metre of air in grammes, or its density, at the time of experiment.

"k" the coefficient of expansion of fluid for 1° Centigrade.

"k'" the coefficient of cubical expansions of the weights for 1° Centigrade.

"δ" the density of the weights at 0° C. to water at maximum density.

We fill the vessel with the fluid, at temperature "t", place it on one pan of the balance, and establish equilibrium by "tare" in the other pan. Having done so, we empty the vessel of its contents, replace it in the pan and reëstablish equilibrium, by adding a weight marked [P], performing all these operations at the temperature "t" and density of air a'; then

$$V(1+\varkappa t)=[P]\frac{(1-\sigma)}{\frac{\triangle}{1+kt}-a'}, \text{ and } \sigma=\frac{a'}{\delta}(1+kt).$$

This formula is of very easy application if the fluid used is mercury, which can be quickly emptied without changing "t" of vessel, and admits of the completion of the weighing without a change in a'. As mercury is readily removable without loss, the filling can be done at any time at any temperature "t'", and this mercury only, without the vessel, can be transferred to the balance and weighed, when the above formula gives $V(1+\varkappa t')$, in place of $V(1+\varkappa t)$. The vessel may be filled at 0° C. and the mercury set aside, until it acquires the temperature "t", to prevent the result being vitiated by condensation of moisture in air on its surface. This cannot be done with water, except the vessel is closed and the whole manipulation and weighing performed at a temperature not exceeding 8° C., and even then a correction for change of volume of vessel would be required, as the water will have to be weighed in the vessel. If specific gravity and "$\varkappa$" of vessel are known, its weight [p] could be previously ascertained, and deducted, in terms of P′, from the weight marked [P′] required to balance the filled flask.

In determining the volume of vessel with water, this should be pure, thoroughly boiled and absorption of air prevented during cooling, until balanced. The vessel should then be emptied, rapidly dried, reduced to the temperature "t", and equilibrium reëstablished by adding weight [P].

REMARKS.

In the above discussion it is assumed that the specific gravity is ascertained by comparing a volume of the substance at 0° C., or of gasses at 0° C. and 760 mm. pres-

sure, under the same "*g'*", under which the original determination of air was made, with an equal volume of pure water at its maximum density. It is also assumed that the c. c. metre contains exactly 1 gramme of such water, when weighed in vacuo. But there is yet doubt about the weight of the present c. c. metre of such water, hence also of its relation to the gramme of the platinum kilogramme of the Archives.

Prof. Miller (l. c.) gives the result of the principal investigations as to the weight of the english cubic inch of water at 62° F. in vacuo, expressed in *doli*, as follows:

French observations: Lefèvre, Gineau and Fabroni (Base du Système Métrique, III., p. 558).....368.365.

English observations: Shuckburgh and Kater (Philos. Trans., London, 1821, Pt. I., p. 326).....368.542.

Swedish observations: Berzelius, Svanberg and Ackermann (Mem. Royal Acad., Stockholm, 1825).....368.474

Austrian observations: Stampfer (Jahrb. K. K. Polytech. Instit., Wien, B. 6, S. 53).....368.237.

Russian observations: Kupffer (Traveaux de la Commis. pour fixe les Meas. et Poids de l'Emp. Russie).....368.361.

Of these, the Russian determination is supposed to be the most accurate.

Prof. Everett in his "Illustrations of the Centigramme—second system of units," London, 1875, p. 18, gives the following table of weight of water contained in a c. c. metre in grammes. It was constructed from Kupffer's observations, as reduced by Prof. Miller, and based on Rosetti's table of expansion.

TABLE OF ABSOLUTE DENSITY OF WATER.

t° C.	Density.	*t*° C.	Density.	*t*° C.	Density.	*t*° C.	Density.	*t*° C.	Density.
0	0.999 884	6	0.999 983	12	0.999 562	18	0.99 8667	24	0.99 7380
1	.999 941	7	946	13	443	19	8473	25	7133
2	.999 982	8	899	14	312	20	8272	26	6879
3	1.000 004	9	837	15	173	21	8060	27	6616
4	1.000 013	10	760	16	015	22	7839	28	6344
5	1.000 003	11	668	17	.998 854	23	7614	30	5778

Therefore, to obtain strictly correct results, the cubic centimetre used should be the same, for which the original determination of its weight of air was made, and the gramme must represent the weight in vacuo of nearly a c. c. metre of that theoretical water, which at 0° C. would represent the unit density.

Regnault determined the volume of the air by means of weight of an equal volume of distilled water; hence, the cubic centimetre in this case is not the c. c. metre of the

standard metre, but the c. c. metre of volume containing 1 standard gramme of water at maximum density ; it is therefore the theoretical, not the existing c. c. metre.

It should also be noted that the table of the volume of mercury is based on temperatures as indicated by the air thermometer. In accurate measurements, therefore, if the temperature was measured by a mercurial thermometer, its indications require a correction. This correction is different with each thermometer, as the expansion of the glass, from which the thermometer tubes are made, changes with the composition of the glass. Hence, we very seldom find mercurial thermometers to correspond, except they are graduated by comparison with the same standard.

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TABLE I. VOLUME OF WATER AT DIFFERENT

	Hallstroem.	Stampfer.	Depretz.	Kopp.	J. S. Pierre.	Hagen.
0	1.000 1082	1.000 133	1.000 1269	1.000 123	1.000 119	1.000 1267
1	0617	061	0730	070	065	0690
2	0281	025	0331	031	028	0289
3	0078	005	0083	008	007	0061
3.75		1.000 000				
3.945						
4	0003	001	1.000 0000	1.000 000	001	0001
4.07						
4.1	1.000 0000					
5	0050	012	0082	006	007	0097
6	0226	038	0309	026	034	0340
7	0527	079	0708	061	072	0725
8	0954	135	1216	109	123	1247
9	1501	205	1879	171		1903
10	2200	289	2684	247	267	2690
11	2970	387	3598	336		3605
12	3888	497	4724	437	461	4645
13	4924	620	5862	552		5808
14	6081	757	7146	679	707	7092
15	7357	906	8751	818		8494
16	8747	1.001 066	1.001 0215	969	998	1.001 0013
17	1.001 0259	239	2067	1.001 133		1645
18	1888	422	3900	307	1.001 331	3390
19	3631	617	5800	493		5246
20	5490	822	79	690	713	7212
21	7460	1.002 039	1.002 00	899		9284
22	9549	265	22	1.002 118		1.002 1461
23	1.002 1746	502	44	348		3741
24	4058	749	71	588	1.002 584	6123
25	6483	1.003 005	93	839		8609
26	9016	271	1.003 21			1.003 1196
27	1.003 1662	545	45			3879
28	4414	828	74	1.003 609	1.003 613	6658
29	7274	1.004 119	1.004 03			9532
30	1.004 0245	418	33			1.004 2501
31		726				1.00 4556
32		1.005 041	1.004 94	1.004 816	1.004 804	4872
33		363				5197
34		694				5530
35		1.006 032	1.005 93			5872
36		375	1.006 24	1.006 172	1.006 142	6223
37		725				6582
38		1.007 081				6950
39		444				7326
40		813	1.007 33	1.007 632	1.007 632	1.00 7711
45						

Temperatures by the Principal Investigators.

Pluecker & Geissler.	Miller.	Mattheissen.	Weider.	Rosetti, 1866.	Rosetti, 1868.
			1.000 081	1.000 1340	1.000 136
				0733	075
			036	0331	032
				0083	008
			014		
	1.000 000				
1.000 000		1.000 000	1.000 000	0002	000
				1.000 0000	
013	008	006		0061	006
038	031	028		0273	029
079	069	066		0620	058
134	121	119		1090	106
204	186	188		1.000 18	
287	265	271		25	246
381	358	369		35	
495	463	479		45	443
	581	604		56	
	712	742		70	691
	854	892		84	
	1.001 009	1.001 054		99	992
	175	227		1.001 16	
	352	412		35	1.001 346
	540	608		55	
	739	814		75	742
	948	1.002 029		97	
	1.002 166	254		1.002 20	
	396	488		42	
	634	731		66	1.002 620
	882	982		90	
		1.003 241		1.003 15	
		507		42	
		780		70	1.003 667
		1.004 059		99	
		345		1.004 28	
		635		57	
		931		87	1.004 889
		1.005 249		1.005 19	
		578		51	
		916		84	
		1.006 261		1.006 19	1.006 275
		616		55	
		979		94	
		1.007 351		1.007 32	
		730		70	1.007 690

Table II. Volume and Density of Water by Rossetti, 1869.

°C.	Density.	Volume.	°C.	Density.	Volume.	°C.	Density.	Volume.
−10	0.998 274	1.001 729	27	0.996 732	1.003 278	64	0.981 40	1.018 95
− 9	556	449	28	460	553	65	0.980 86	1.019 51
− 8	814	191	29	179	835	66	31	1.020 08
− 7	0.999 040	1.000 963	30	0.995 894	1.004 123	67	0.979 77	65
− 6	241	756	31	0.995 60	1.004 42	68	21	1.021 24
− 5	428	573	32	30	73	69	0.978 64	83
− 4	584	416	33	0.994 98	1.005 05	70	07	1.022 43
− 3	719	281	34	65	38	71	0.977 49	1.023 03
− 2	832	168	35	31	72	72	0.976 90	65
− 1	926	074	36	0.993 96	1.006 08	73	31	1.024 27
0	1.000 000	1.000 000	37	60	45	74	0.975 71	90
+ 1	057	0.999 943	38	23	82	75	11	1.025 53
2	098	902	39	0.992 86	1.007 19	76	0.974 50	1.026 17
3	120	880	40	48	57	77	0.973 89	81
4	129	871	41	10	96	78	28	1.027 49
5	119	881	42	0.991 71	1.008 36	79	0.972 67	1.028 09
6	099	901	43	31	76	80	06	74
7	062	938	44	0.990 91	1.009 17	81	0.971 45	1.029 39
8	015	985	45	50	58	82	0.970 83	1.030 05
9	0.999 953	1.000 047	46	09	1.010 01	83	20	72
10	876	124	47	0.989 67	44	84	0.969 56	1.031 39
11	784	216	48	23	88	85	0.968 92	1.032 07
12	678	322	49	0.988 78	1.011 34	86	28	76
13	559	441	50	33	81	87	0.967 64	1.033 45
14	429	572	51	0.987 87	1.012 29	88	0.966 99	1.034 14
15	289	712	52	41	78	89	34	84
16	131	870	53	0.986 94	1.013 27	90	0.965 68	1.035 54
17	0.998 970	1.001 031	54	46	76	91	02	1.036 25
18	782	219	55	0.985 98	1.014 25	92	0.964 15	97
19	588	413	56	50	74	93	0.963 68	1.037 70
20	388	615	57	01	1.015 24	94	00	1.038 44
21	176	828	58	0.984 50	74	95	0.962 31	1.039 18
22	0.997 953	1.002 049	59	01	1.016 25	96	0.961 61	93
23	730	276	60	0.983 51	77	97	0.960 91	1.040 69
24	495	511	61	0.982 99	1.017 31	98	20	1.041 45
25	249	759	62	47	85	99	0.959 49	1.042 22
26	0.996 994	1.003 014	63	0.981 94	1.018 39	100	0.958 78	1.043 00

Table III. Volume of Water for Degrees of Centigrade.

° C.	Volume.	Diff.	Log. Volume.	° C.	Volume.	Diff.	Log. Volume.
0	1.000 129			21	1.001 957	213	
		57	0.000 0560			220	0.000 8491
1	072	41	0313	22	.002 177	228	9444
2	031	22	0135	23	405	236	.001 0432
3	009	9	0039	24	641	247	1 1456
4	1.000 000	10	0.000 0000	25	888	256	1 2524
5	010	20	0043	26	.003 144	264	1 3633
6	030	37	0130	27	408	274	1 4776
7	067	47	0291	28	682	283	1 5961
8	114	62	0495	29	965	288	1 7186
9	176	77	0764	30	.004 253	30	1 8431
10	253	92	0.000 1099	31	1.004 55	31	1 9716
11	345	106	1498	32	4 86	32	2 1056
12	451	119	1958	33	5 18	33	2 2438
13	570	131	2475	34	5 51	35	2 3864
14	701	140	3043	35	5 86	35	2 5375
15	841	158	3651	36	6 21	36	2 6886
16	999	167	4337	37	6 57	37	2 8440
17	.001 160	188	5035	38	6 94	38	3 0036
18	348	194	5851	39	7 32	38	3 1675
19	542	202	6692	40	7 70		3 3313
20	744		7567				

Table V. Volume of Mercury for Degrees of Centigrade.

° C.	Volume.	Log. Volume.	° C.	Volume.	Log. Volume.
0	1.000 000 00	0.000 0000	21	1.003 770 27	0.001 6343
1	179 03	0777	22	950 36	7122
2	358 11	1555	23	1.004 130 50	7902
3	357 25	2333	24	310 69	8681
4	716 43	3110	25	490 94	9460
5	895 66	3888	26	671 23	0.002 0239
6	1.001 074 95	4666	27	851 57	1019
7	254 28	5444	28	1.005 031 97	1799
8	433 67	6222	29	212 41	2578
9	613 10	0.000 7000	30	392 91	3358
10	792 59	7778	31	573 45	4138
11	972 13	8556	32	754 05	4918
12	1.002 151 74	9335	33	934 70	5698
13	331 35	0.001 0113	34	1.006 115 39	6478
14	511 04	0892	35	296 14	7258
15	690 78	1670	36	476 94	8038
16	870 57	2449	37	657 79	8819
17	1.003 050 41	3228	38	838 69	9599
18	230 29	4006	39	1.007 019 64	0.003 0379
19	410 24	4785	40	200 64	1160
20	590 23	5564			

Table IV. Volume of Water for Degrees of Fahrenheit.

° F.	Volume.	Diff.	Log. Volume.	F.	Volume.	Diff.	Log. Volume.
32	1.000 129		0.000 0560	68	1.001 744	114	0.000 7568
33	095	34	0413	69	861	117	8075
34	066	29	0287	70	981	120	8595
35	043	23	0187	71	1.002 103	122	9124
36	025	18	0109	72	228	125	9665
37	011	14	0048	73	355	127	0.001 0216
38	004	7	0017	74	485	130	0779
39	000	4	0000	75	617	132	1351
40	003	3	0013	76	751	134	1931
41	010	7	0043	77	888	137	2524
42	020	10	0087	78	1.003 028	140	3131
43	035	15	0152	79	171	143	3750
44	054	19	0235	80	317	146	4382
45	077	23	0334	81	466	149	5027
46	104	27	0452	82	618	152	5684
47	135	31	0586	83	772	154	6351
48	170	35	0738	84	929	157	7030
49	210	40	0912	85	1.004 089	160	7722
50	253	43	1099	86	253	164	8431
51	301	48	1307	87	420	167	9153
52	353	52	1533	88	590	170	9889
53	409	56	1776	89	763	173	0.002 0636
54	470	61	2041	90	939	176	1397
55	535	65	2323	91	1.005 118	179	2170
56	605	70	2627	92	300	182	2957
57	679	74	2948	93	485	185	3756
58	758	79	3291	94	673	188	4568
59	841	83	3651	95	864	191	5393
60	927	86	4024	96	1.006 057	193	6226
61	1.001 016	89	4410	97	253	196	7072
62	109	93	4814	98	452	199	7931
63	206	97	5234	99	653	201	8798
64	307	101	5673	100	857	204	9678
65	411	104	6124	101	1.007 064	207	0.003 0571
66	519	108	6592	102	274	210	1476
67	630	111	7073	103	487	213	2395
				104	703	216	3326

Table VI. Volume of Mercury for Degrees of Fahrenheit.

$t.°$ F.	Volume.	Log. of Volume.	$t.°$ F.	Volume.	Log. of Volume.
32	1.000 000 00	0.000 0000	68	1.003 590 23	0.001 5564
33	099 46	0432	69	690 24	5997
34	198 93	0864	70	790 27	6430
35	298 14	1295	71	890 32	6863
36	397 92	1728	72	990 39	7296
37	497 44	2160	73	1.004 090 46	7728
38	596 97	2592	74	190 56	8161
39	696 52	3024	75	290 67	8594
40	796 08	3456	76	390 80	9027
41	895 66	3888	77	490 94	9460
42	995 26	4320	78	591 09	9893
43	1.001 094 71	4752	79	691 27	0.002 0326
44	194 50	5185	80	791 45	0759
45	294 14	5617	81	891 66	1192
46	393 80	6049	82	991 88	1625
47	493 47	6481	83	1.005 092 11	2059
48	593 16	6914	84	192 36	2492
49	692 87	7346	85	292 63	2925
50	792 59	7778	86	392 91	3358
51	892 36	8211	87	493 21	3791
52	992 08	8643	88	593 52	4225
53	1.002 091 85	9075	89	693 85	4658
54	191 63	9508	90	794 19	5091
55	291 43	9940	91	894 55	5525
56	391 24	0.001 0373	92	994 92	5958
57	491 07	0805	93	1.006 095 31	6391
58	590 92	1238	94	195 72	6825
59	690 78	1669	95	296 14	7258
60	790 65	2103	96	396 58	7692
61	890 55	2535	97	497 03	8125
62	990 45	2968	98	597 50	8559
63	1.003 090 38	3401	99	697 98	8992
64	190 32	3833	100	798 48	9426
65	290 27	4266			
66	390 24	4699	39.2	1.000 716 43	0.000 3110
67	490 22	5131	39.101	706 57	3067

Table VII. Tension of Mercurial Vapor for Degrees Centigrade.

$t.°$ C.	Tension in millimetres.	$t.°$ C.	Tension in millimetres.	$t.°$ C.	Tension in millimetres.	$t.°$ C.	Tension in millimetres.
0	0.0200	11	0.0276	21	0.0385	31	0.0549
1	.0206	12	.0285	22	.0399	32	.0570
2	.0212	13	.0295	23	.0413	33	.0591
3	.0218	14	.0304	24	.0428	34	.0612
4	.0223	15	.0314	25	.0443	35	.0634
5	.0231	16	.0325	26	.0459	36	.0659
6	.0237	17	.0336	27	.0475	37	.0685
7	.0244	18	.0347	28	.0493	38	.0712
8	.0252	19	.0359	29	.0511	39	.0739
9	.0260	20	.0372	30	.0530	40	.0767
10	.0268						

Table VIII. Tension of Mercurial Vapor for Degrees Fahrenheit.

$t.°$ F.	Tension in English inches.	$t.°$ F.	Tension in English inches.	$t.°$ F.	Tension in English inches.
32	0.0008	57	0.0012	81	0.0019
33	.0008	58	.0012	82	.0019
34	.0008	59	.0013	83	.0020
35	.0008	60	.0013	84	.0020
36	.0008	61	.0013	85	.0020
37	.0009	62	.0013	86	.0021
38	.0009	63	.0013	87	.0021
39	.0009	64	.0014	88	.0021
40	.0009	65	.0014	89	.0022
41	.0009	66	.0014	90	.0022
42	.0009	67	.0014	91	.0023
43	.0009	68	.0015	92	.0023
44	.0010	69	.0015	93	.0024
45	.0010	70	.0015	94	.0024
46	.0010	71	.0015	95	.0025
47	.0010	72	.0016	96	.0025
48	.0010	73	.0016	97	.0026
49	.0010	74	.0016	98	.0026
50	.0010	75	.0016	99	.0027
51	.0011	76	.0017	100	.0027
52	.0011	77	.0017	101	.0028
53	.0011	78	.0018	102	.0028
54	.0011	79	.0018	103	.0029
55	.0012	80	.0019	104	.0030
56	.0012				

Table IX. Factors to Reduce Barometrical Column to Freezing Point for Centigrade.

$t.°$ C.	ζ.	Log. ζ.	$t.°$ C.	ζ.	Log. ζ.
1	0.000 160 24	$\bar{4}$.204 7745	21	0.003 363 63	$\bar{3}$.526 8080
2	320 48	.505 7945	22	523 72	.547 0014
3	480 71	.681 8847	23	683 80	.566 2964
4	640 93	.806 8112	24	843 88	.584 7699
5	801 14	.903 7097	25	0.004 003 96	.602 4896
6	961 36	.982 8845	26	164 02	.619 5127
7	0.001 121 55	$\bar{3}$.049 8199	27	324 07	.635 8928
8	281 75	.107 8041	28	484 13	.651 6778
9	441 93	.158 9454	29	644 16	.666 9075
10	602 12	.204 6945	30	804 20	.681 6212
11	762 29	.246 0785	31	964 22	.695 8512
12	922 48	.283 8626	32	0.005 124 24	.709 6299
13	0.002 082 61	.318 6079	33	284 25	.722 9833
14	242 77	.350 7844	34	444 26	.735 9385
15	402 92	.380 7383	35	604 26	.748 5179
16	563 05	.408 7575	36	764 25	.760 7425
17	723 18	.435 0768	37	924 23	.772 6317
18	883 30	.459 8893	38	0.006 084 20	.784 2036
19	0.003 043 42	.483 3621	39	244 17	.795 4746
20	203 53	.505 6286	40	404 13	.806 4599

Table X. Factors to Reduce Barometrical Column to Freezing Point for Fahrenheit.

° F.	ζ′.	Log. ζ′.	° F.	ζ′.	Log. ζ′.
32	0.000 312 57	$\bar{4}$.494 9473	67	0.003 426 19	$\bar{3}$.534 8117
33	401 57	.603 7613	68	515 10	.545 9375
34	490 56	.690 7807	69	604 02	.556 7872
35	579 55	.763 0887	70	692 97	.567 3762
36	668 54	.825 1300	71	781 87	.577 7062
37	757 53	.879 4016	72	870 79	.587 8000
38	846 52	.927 6396	73	959 70	.597 6626
39	935 51	.971 0477	74	0.004 048 60	.607 3163
40	0.001 024 59	$\bar{3}$.010 5181	75	137 47	.616 7346
41	113 46	.046 6757	76	226 40	.625 9709
42	202 44	.080 0646	77	315 28	.635 0090
43	291 42	.111 0662	78	404 22	.643 8690
44	380 39	.140 0021	79	493 09	.652 5454
45	469 36	.167 1277	80	581 96	.661 0509
46	558 33	.192 6589	81	670 86	.669 3970
47	647 30	.216 7726	82	759 75	.677 5841
48	736 26	.239 6157	83	848 61	.685 6172
49	825 24	.261 3200	84	937 51	.693 5082
50	914 19	.281 9847	85	0.005 026 41	.701 2578
51	0.002 003 18	.301 7198	86	115 26	.708 8681
52	092 15	.320 5932	87	204 15	.716 3500
53	181 11	.338 6770	88	293 02	.723 7037
54	270 04	.356 0344	89	381 90	.730 9353
55	358 94	.372 7178	90	470 76	.738 0478
56	447 91	.388 7948	91	559 63	.745 0457
57	536 85	.404 2948	92	648 52	.751 9344
58	625 77	.419 2578	93	737 35	.758 7113
59	714 74	.433 7275	94	826 21	.765 3862
60	803 57	.447 7108	95	915 07	.771 9597
61	892 56	.461 2817	96	0.006 003 94	.778 4366
62	981 52	.474 4383	97	092 79	.784 8158
63	0.003 070 47	.487 2050	98	181 64	.791 1034
64	159 41	.499 6061	99	270 48	.797 3008
65	248 32	.511 6591	100	359 33	803 4110
66	337 27	.523 3907			

Table XI. Correction to be Applied to Observations of English Barometer with Brass Scales to Reduce to Freezing Point.

° F.	Tension mercurial vapor.	31 inches.	30 inches.	29 inches.	28 inches.	Diff. for 0.1 (0.0000,)	° F.	Tension mercurial vapor.	31 inches.	30 inches.	29 inches.	28 inches.	Diff. for 0.1 (0.0000,)
32	0.0008	0.0097	0.0094	0.0091	0.0088	0,31	66	0.0014	0.1035	0.1001	0.0968	0.0934	3.34
33		.0124	.0121	.0117	.0112	0,40	67		.1062	.1028	.0994	.0959	3.43
34		.0152	.0147	.0142	.0137	0,49	68	0.0015	.1090	.1055	.1019	.0984	3,52
35		.0180	.0174	.0168	.0162	0,58	69		.1117	.1081	.1045	.1009	3.60
36		.0207	.0201	.0194	.0187	0,67	70		,1145	.1108	.1071	.1034	3.69
37	0.0009	.0235	.0227	.0220	.0212	0,76	71		.1172	.1135	.1097	.1059	3,78
38		.0262	.0254	.0246	.0237	0,85	72	0.0016	.1200	.1161	.1123	.1084	3 87
39		.0290	.0281	.0271	.0262	0,94	73		.1228	.1188	.1148	.1109	3,96
40		.0318	.0307	.0297	.0287	1,02	74		.1255	.1215	.1174	.1134	4,05
41		.0345	.0334	.0323	.0312	1,11	75		.1283	.1241	.1200	.1158	4.14
42		.0373	.0361	.0349	.0337	1,20	76	0.0017	.1310	.1268	.1226	.1183	4,23
43		.0390	.0387	.0375	.0362	1,29	77		.1338	.1295	.1251	.1208	4,32
44	0.0010	.0428	.0414	.0400	.0387	1,38	78	0.0018	.1365	.1321	.1277	.1233	4,40
45		.0456	.0441	.0426	.0411	1,47	79		.1393	.1348	.1303	.1258	4,49
46		.0483	.0468	.0452	.0436	1,56	80	0.0019	.1420	.1375	.1329	.1283	4.58
47		.0511	.0494	.0478	.0461	1,65	81		.1448	.1401	.1356	.1308	4,67
48		.0538	.0521	.0504	.0486	1,74	82		.1475	.1428	.1380	.1333	4,76
49		.0566	.0548	.0529	.0511	1,83	83	0.0020	.1513	.1465	.1416	.1368	4,85
50		.0593	.0574	.0555	.0536	1,91	84		.1531	.1481	.1432	.1383	4,94
51	0.0011	.0621	.0601	.0581	.0561	2,00	85		.1558	.1508	.1457	.1407	5.03
52		.0649	.0628	.0607	.0586	2,09	86	0.0021	.1585	.1535	.1483	.1432	5.12
53		.0676	.0654	.0633	.0611	2,18	87		.1613	.1561	.1509	.1457	5,20
54		.0704	.0681	.0658	.0636	2,27	88		.1641	.1588	.1535	.1482	5,29
55	0.0012	.0731	.0708	.0684	.0661	2,36	89	0.0022	.1668	.1615	.1561	.1507	5,38
56		.0759	.0734	.0709	.0685	2,46	90		.1696	.1641	.1587	.1532	5,47
57		.0786	.0761	.0736	.0710	2,54	91	0.0023	.1723	.1668	.1612	.1557	5,56
58		.0814	.0788	.0761	.0735	2,63	92		.1751	.1695	.1638	.1582	5,65
59	0.0013	.0842	.0814	.0787	.0760	2.71	93	0.0024	.1779	.1721	.1664	.1606	5,74
60		.0869	.0841	.0813	.0785	2,80	94		.1806	.1748	.1690	.1631	5,83
61		.0897	.0868	.0839	.0810	2,89	95	0.0025	.1834	.1775	.1715	.1656	5,92
62		.0924	.0894	.0865	.0835	2,98	96		.1861	.1801	.1741	.1681	6,00
63		.0952	.0921	.0890	.0860	3,07	97	0.0026	.1889	.1828	.1767	.1706	6,09
64	0.0014	.0979	.0948	.0916	.0885	3,16	98		.1916	.1854	.1793	.1731	6,18
65		.1007	.0974	.0942	.0910	3,25	99	0.0027	.1944	.1881	.1818	.1756	6,27

Table XII. Elastic Force of Aqueous Vapor for Degrees Centigrade in Millimetres.

° C.	Millimetre.	° C.	Millimetre.	° C.	Millimetre.
−10	2.078	7	7.492	24	22.184
− 9	2.261	8	8.017	25	23.550
− 8	2.456	9	8.574	26	24.988
− 7	2.666	10	9.165	27	26.505
− 6	2.890	11	9.792	28	28.101
− 5	3.131	12	10.457	29	29.782
− 4	3.387	13	11.162	30	31.548
− 3	3.662	14	11.908	31	33.406
− 2	3.955	15	12.699	32	35.359
− 1	4.267	16	13.536	33	37.410
0	4.600	17	14.421	34	39.565
1	4.940	18	15.357	35	41.827
2	5.302	19	16.346	36	44.201
3	5.687	20	17.391	37	46.691
4	6.097	21	18.495	38	49.302
5	6.534	22	19.659	39	52.039
6	6.998	23	20.888	40	54.906

Table XIII. Elastic Force of Aqueous Vapor in English Inches for Degrees Fahrenheit.

° F.	English inches.	° F.	English inches.	° F.	English inches.	° F.	English inches.	° F.	English inches.
14	0.0818	32	0.1811	50	0.3608	68	0.6847	86	1.2421
15	0.0857	33	0.1883	51	0.3743	69	0.7084	87	1.2821
16	0.0898	34	0.1959	52	0.3882	70	0.7329	88	1.3234
17	0.0940	35	0.2037	53	0.4027	71	0.7583	89	1.3659
18	0.0984	36	0.2119	54	0.4176	72	0.7844	90	1.4097
19	0.1030	27	0.2204	55	0.4331	73	0.8113	91	1.4546
20	0.1078	38	0.2291	56	0.4490	74	0.8391	92	1.5008
21	0.1128	39	0.2382	57	0.4655	75	0.8676	93	1.5482
22	0.1179	40	0.2476	58	0.4825	76	0.8970	94	1.5969
23	0.1233	41	0.2572	59	0.5000	77	0.9272	95	1.6468
24	0.1289	42	0.2672	60	0.5179	78	0.9582	96	1.6980
25	0.1347	43	0.2775	61	0.5365	79	0.9902	97	1.7508
26	0.1407	44	0.2882	62	0.5558	80	1.0232	98	1.8050
27	0.1469	45	0.2993	63	0.5756	81	1.0572	99	1.8607
28	0.1534	46	0.3108	64	0.5962	82	1.0922	100	1.9179
29	0.1600	47	0.3228	65	0.6173	83	1.1281	101	1.9766
30	0.1688	48	0.3351	66	0.6392	84	1.1651	102	2.0368
31	0.1739	49	0.3477	67	0.6616	85	1.2031	103	2.0985

NOTES

ON

THE USE OF LOGARITHMS.

READ BEFORE THE ESSAYONS CLUB OF THE CORPS OF ENGINEERS,

APRIL 14, 1879;

BY

H. S. PALFREY,
CIVIL ENGINEER.

NO. XLVI. PRINTED PAPERS.

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NOTES ON THE USE OF LOGARITHMS.

A paper read before the "ESSAYONS CLUB" of the Corps of Engineers, on April 14th, 1879, by H. G. Palfrey, Civil Engineer.

There are certain uses required to be made of logarithms that are not usually fully explained in tbe text books upon that subject. As they somtimes prove perplexing, it may be worth while to offer some considerations which will suggest their solution.

The principles upon which the uses of logarithms are based are two: first, a logarithm is in fact an exponent, whether positive or negative; and second, a logarithm is an algebraic binomial, of which one part, the mantissa, is always positive; while the other, the characteristic may be positive or negative. The first principle is fundamental; the theory of logarithms could never be explained without stating it. The second results from the form in which it is found most convenient to use them; they could be used without any reference to it. Perhaps for this reason it is not always clearly stated in the text books. The advantage gained by writing a negative logarithm in the form universally adopted, is that the mantissa, the only number given in the tables, is the same for the same combination of figures, without regard to the position of the decimal point. If the whole of the logarithm of a proper fraction were negative, it would of course be numerically equal to the logarithm of its reciprocal; and it would be much less convenient to find in the tables than under the present system.

No doubt can arise as to the treatment of positive logarithms; they can be used in all respects like other abstract numbers. In the case of negative logarithms—and all logarithms with negative characteristics are necessarily negative, since the positive part, being a fraction, must be less than the negative part, which is an integer—the binomial character of the logarithm as usually written must always be kept in mind. In the ordinary processes of addition and subtraction, and of multiplication by a multiplier of a single figure, the proper course to take is obvious. In dividing by a single figure, the rule usually given where any is given, namely, to add to the characteristic the least in-

teger that will make it exactly divisible, and then to "carry" the same figure to the left of the mantissa, as in ordinary division, is evidently correct; as by this process the logarithm to be divided is first diminished and then increased by the same amount. But in multiplying or dividing by numbers of more than one figure, the binomial character of the negative logarithm becomes important, and must not be overlooked.

In the case of multiplication, the only precaution to be observed is to mark those parts of the different products that are negative; and in the final summing up, to pay due attention to the signs. Observing, however, that inasmuch as the mantissa is to be entirely positive, if any of the columns to the right of the decimal point have a negative sum, that result is to be taken from ten, the difference to be set down as the sum of that column, and the sum of the next column to the left to be diminised by 1, algebraically; which is equivalent to "carrying" negatively, instead of positively as in common arithmetical addition. An analogous operation is to be performed if one of the columns to the left of the decimal point has a positive sum, since the characteristic is to be negative. The occurrence of positive and negative figures in the same column can be easily avoided, however, if desired. To illustrate by an example; let it be proposed to multiply the logarithm $\overline{3}.8219$ by 2.8.

$$\begin{array}{r} \overline{3}.8219 \\ 2.8 \\ \hline \overline{1}.\overline{8}5752 \\ \overline{5}.6438 \\ \hline \overline{7}.90132 \end{array}$$

The multiplications by the two figures of the multiplier are performed; the negative parts of the products are distinguished from the positive parts; and the addition is made as usual, until we come to the column to the right of the decimal point. If the usual course of addition were followed here, the logarithm would take the form $\overline{6}.\overline{1}0132$, which would not be found in the logarithmic tables. But $-6.1=\overline{7}+0.9$; so that by thus changing the form without interfering with its value, we have the logarithms as usually written. This complication might have been avoided by making this change in the form of the first product, and writing it $\overline{2}.25752$ instead of $\overline{1}.\overline{8}5752$, which would have given directly, as before:

$$\begin{array}{r} \overline{2}.25752 \\ \overline{5}.6438 \\ \hline \overline{7}.90132 \end{array}$$

The change must be made somewhere, in such a case as this, and where it shall be made is a matter of choice.

Had the multiplier been negative instead of positive, a change of signs gives for

the product $7-0.90132$. To bring this binomial into the usual logarithmic form, with a positive mantissa, it is merely necessary to perform the subtraction indicated :—

$$\begin{array}{r} 7.00000 \\ 0.90132 \\ \hline 6.09868. \end{array}$$

With regard to division, the difficulty occurs at the point where a part of the figures of the dividend considered are positive and a part negative. As we are assuming that the divisor has at least two figures, and it seldom happens that the characteristic of a logarithm is so large as 100, this is likely to be at the first figure of the quotient. Bearing in mind that the whole of the mantissa is to be positive, it is evident that the first remainder must be positive ; and therefore the product of the first (negative) figure of the quotient by the divisor must be larger than the first figures of the dividend supposed to contain it. This consideration leads to the rule given for dividing a logarithm with a negative characteristic by a divisor of one figure: "Add to the characteristic the least number that will make it exactly divisible," etc. After the division of the characteristic and the obtaining of the first remainder, everything goes on in the usual course of long division. As an example, let us take the converse of our example in multiplication, and and divide $\bar{7}.90132$ by 2.8.

$$\begin{array}{rl} 2.8) & \bar{7}.90132\ (\bar{3}.8219 \\ & -8\ 4 \\ \hline & 230 \\ & 224 \\ \hline & 61 \\ & 56 \\ \hline & 53 \\ & 28 \\ \hline & 252 \\ & 252 \\ \hline \end{array}$$

The first product, -8.4, is subtracted algebraically instead of arithmetically ; in fact, the whole process is that of the division of an algebraic binomial, with numerical instead of literal terms. If the division had been negative instead of positive, the same transformation would have become necessary as in the case of a negative multiplier.

These multiplications and divisions can also be performed, conveniently, by subtracting the positive mantissa from the negative characteristic of the logarithm, written as above ; treating the difference as a negative quantity ; and, after finishing the operation, transforming the result if negative into a logarithm of the usual form. For instance, instead of $\bar{3}.8219$, in the example taken for multiplication, write :

$-2.1781 \times 2.8 = -6.09868 = -7 + 0.90132$, or as usually written $\bar{7}.90132$;
i. e. the same result obtained by the other process. This method may sometimes prove to be more convenient than the other. It is especially likely to be so in the use of formulas into which logarithms enter as coefficients or constants. To take an example that once arose in my own practice; I had a number of equations of condition of the form $\frac{\log.(fw)}{\log. C} - \frac{\log. B}{\log. C} = A$, in which the variables were A and B, to combine by the method of least squares. In some of them log. C was negative, and would have been troublesome to handle under the usual form; but by means of this transformation the denominators of the fractions were rendered monomial, and the necessary multiplications and divisions were simplified.

By carefully bearing in mind the binomial character of negative logarithms, or by rendering them monomial as above indicated, no uncertainty can arise in making any required use of them.

TESTING

OF

MEDIUM & HIGH TENSION FUZES.

READ BEFORE THE ESSAYONS CLUB OF THE CORPS OF ENGINEERS,

MAY 28, 1879;

BY

BVT. BRIG. GEN. HENRY L. ABBOT,
MAJOR OF ENGINEERS.

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TESTING OF MEDIUM AND HIGH TENSION FUZES.

A paper read* before the "ESSAYONS CLUB" of the Corps of Engineers, on May 28, 1879, by Bvt. Brig. Gen. Henry L. Abbot, Corps of Engineers.

In 1869, when investigations in submarine mining were systematically begun at Willet's Point, most of the fuzes in the market were designed for frictional electricity and were primed with fulminating copper, which had been patented by Dowse two years before. Serious accidents were frequent from the over sensitiveness of this priming; and the need of some method by which a safe fuze could be selected was urgently felt. But such a method would require apparatus for comparing the sensitiveness of different primings by accurate measurement; and as nothing of the kind had been devised, or at least made public, the task was undertaken at once.

Testing Apparatus. Medium and high tension fuzes generally admit of no individual test to determine in advance their certainty of action, in so much as this chiefly depends on the chemical nature and condition of the priming. The new plan which I sought to develope, involves a machine by which known and gradually increasing charges can successively be passed through this priming; beginning with a charge too small to cause ignition, and successively increasing it by small known increments until explosion occurs, will fully test the individual fuze under trial; and by applying this process to a sufficient number charged with the particular priming to be studied, a good idea both as to its absolute sensitiveness and as to its uniformity of action, can be formed.

Such a machine, although simple in theory, was by no means easy to devise; for the sensitiveness of some of the primings required it to possess extraordinary delicacy.

After careful consideration, I adopted the idea of Cuthbertson's balance electrometer as promising the best results. Many practical difficulties, not necessary to recount here, were successively overcome before the requisite degree of sensitiveness was secured.

* An abstract of this paper was read before the National Academy of Sciences, on April 17, 1879.

The machine as finally perfected in June, 1871, may be described as follows:

A wooden stand, 16×4.5 inches, supports two uprights, each about 6 inches long.

One is nearly in the middle of the stand. It is of ebonite, insulating a nickel-plated brass hemisphere secured, flat side up, on its top. A deep groove across the flat side separates two little holes, one inch apart, of which the bottoms are plane surfaces. They are filled with pure mercury, and support the needle points of a curved steel ribbon secured, near its middle point, to a light aluminum rod, 13 inches long. This rod has a gilded pith ball at one end, and a little bit of rounded soft iron at the other. Its total weight, including the steel ribbon, is 32 grains; of which the inertia only is to be overcome when adjusted for extreme delicacy. A nickle plated brass arm, projecting from the side of the hemispherical ball, supports at the same level a small nickel-plated brass ball, with a plane top. When the aluminum rod is in position, the needle points stand in the mercury, and the pith ball rests on the top of the small brass ball. The space between the needle points and the pith ball is graduated into 100 divisions, over which slides a little aluminum weight adjusted to register one grain when at the 100 mark. When this weight rests at zero, the rod is to be accurately balanced by an ivory slide moving on its other half.

Exactly under the soft iron terminal is placed the second upright. It consists of a hollow glass tube, capped by a nickel-plated brass sphere pierced with a vertical hole. Contained within the glass tube, with one end slightly projecting above the sphere, is a little magnet. By a vertical sliding motion which can be given to the upright, the distance between the magnet and the soft iron terminal can be regulated on an attached scale at pleasure. The usual distance is half an inch.

The projecting arm of the middle upright is connected by an insulated wire with a mercury cup on the stand; which is also similarly connected with the positive conductor of an electrical machine, made after the Smith pattern; and also with the inner coating of a condenser of which the other terminal is put to earth. Condensers of various capacity from 0.00016 microfarads upwards are employed, all suited for high potentials. The negative conductor of the electrical machine, also, is put to earth.

One insulated lead wire of the fuze to be tested, is put to earth; and the other, to the brass ball of the magnet upright. All sharp ends of lead wires are coated with sealing wax, to prevent leakage.

When the electrical machine is excited, the positive electricity passes through the mercury cup on the stand to the condenser, and charges it to a degree proportional to the potential of its free electricity—the latter is also equally distributed over the prime conductor and the whole apparatus supported by the middle insulated upright. When

this potential becomes sufficiently great to overcome, by the repulsion acting on the pith ball, the inertia of the aluminum rod (loaded to any desired degree by the movable weight) the pith ball rises. The soft iron terminal, already in the magnet field, is then instantly attracted and brought by the magnet into contact with the brass ball supporting it. The condenser is thus discharged through the fuze; which is exploded, or not, according to its degree of sensitiveness. A small gold leaf or pith ball electroscope, connected with the inner coating of the condenser, reveals the proper working of the instrument to the eye. Care must, of course, be taken to avoid any dampness on the apparatus, and to move the handle of the electrical machine steadily and uniformly—stopping at the instant the pith ball begins to move.

By beginning with a charge known to be too feeble, and increasing gradually by small regular increments, the exact minimum amount required to effect an explosion is ascertained. Applying this test to a sufficient sample, the character for uniformity and sensitiveness of any lot of high or medium tension fuzes may be determined; and by a subsequent repetition any change caused by lapse of time may be detected.

This apparatus is so delicate, that although severe shocks may be given if desired, more than one hundred successive charges, each larger than the preceeding by a definite quantity, may be sent through the human body before the senses begin to take note of them.

Coefficients of the Electrometer. This electrometer, of course, registers its results in terms of the electrical repulsion exerted between the fixed brass ball and the movable pith ball; i. e., its natural scale is entirely arbitrary. To reduce the readings to recognized electrical units, was desirable for several reasons and it was accomplished in the following manner.

The explosion of the fuze is caused by the passage through it of the charge of the condenser increased by the free electricity distributed over the insulated part of the apparatus. This total charge is measured by the product of the sum of the capacities of the condenser (K) and of the insulated surface (K_1) expressed in microfarads, by the difference of potential between the opposed plates (P) expressed in volts. To send this charge through the fuze, the repulsive force acting between the fixed brass ball and the movable pith ball must raise the weight registered on the scale in hundredths of grains (F), increased by the resistance opposed by the inertia of the movable arm (F'). But by the well known law of Coulomb, the repulsive force between two bodies similarly charged with electricity, is proportional to the product of their charges — a product which in this case may be assumed to be proportional to the square of the total charge. Hence we have the fundamental equation of the machine:

$$(1) \quad \cdots \quad (K+K_{,})P = A\sqrt{F+F'}$$

In this equation K and $K_{,}$ admit of exact measurement, F′ and A (the latter for a given condenser) are constants, and F is the reading of the electrometer scale. Hence if any plan can be devised by which a series of numerical values for the first member corresponding to known values of F can be determined, the values of A and F′ can be found by the method of least squares. This done, by noting F it will be easy to compute for any charge which is sent through the fuze both the quantity in microfarads and the potential in volts. These determinations were made in the following manner.

In a Thomson reflecting galvanometer, the swings of the beam of light, corrected in the usual way for the resistance of the air, etc., are proportional to the charges sent through the coils; i. e., in this case to $(K+K_{,})P$. The numerical values of K for any condenser, and that of $K_{,}$ as well, may be found from a standard condenser by Law's method. By the same method, the value of P (electromotive force in volts) may be found for any battery by comparing its swing with that of a standard Clark cell whose electromotive force in volts is known.

Hence, by placing a Thomson reflecting galvanometer in place of the fuze with my apparatus, noting the swings corresponding to a series of known values of F, and comparing the latter with swings produced by known charges of a standard condenser expressed in microfarads, the desired result may be accomplished. This was done in the spring of 1874.*

Several condensers differing in capacity were needful to adapt the apparatus to fuzes of different degrees of sensitiveness. A small Leyden jar, whose inner and outer coatings were each 39 square inches, was used at first; but after April, 1874, it was usually replaced by other condensers better suited for so delicate work. Of these, one known as the mica condenser was made at Willet's Point, by bedding in paraffine wax two plates of tin-foil, separated by a sheet of mica. Each plate contained 4 square inches

* It may be well to remark that the practical use of the apparatus was not delayed until the results of this analysis had been reached. As soon as the electrometer was perfected, and even before the final form had been adopted, the various fuzes in the market were tested; original primings were submitted to experiment; and the manufacturers of electrical fuzes in this country were encouraged to present new compositions for trial. This was frequently done, and with the happiest results; for by this means the dangerous fulminating copper priming was replaced by safe compositions, and the needless sacrifice of life on the Hoosac tunnel and other public works was brought to an end. Letters from these gentlemen, now on file at Willet's Point, attest these facts, and establish the practical utility of a systematic study of the problem. The natural scale of the electrometer was employed in this work; i. e., the fuzes were compared by the electrical repulsion in hundredths of grains Troy needful to send a charge sufficiently large to cause their explosion.

of surface. Two other condensers, designated respectively as No. 1 and No. 2, were subsequently made to order by the Laflin & Rand Powder Company of New York. The former consisted of two plates of tin-foil 3 inches in diameter, bedded $\frac{1}{32}$ of an inch apart in soft ebonite subsequently vulcanized. The latter was identical in construction, but the plates were 6 inches in diameter. The capacities of these four condensers were very carefully determined, by comparing them with two standards made in London—one (half a microfarad) by Elliott Bros., and the other (one-third of a microfarad) by Warden & Co. These two standards differed less than one per cent. from each other, and the mean of their indications was adopted. The following table exhibits the results of several measurements of these fuze testing condensers made at different dates, in different places, by different observers, and with widely different battery power. The means are adopted in the final reductions, now reported.

CAPACITY OF FUZE TESTING CONDENSERS.

Date.	Cells used.		Measured capacity in microfarads.				
	Number.	Elect. force.	Apparatus without condenser.	Leyden jar.	Mica condenser.	Condenser No. 1.	Condenser. No. 2.
Feb. 11, 1874.	50	59.0		0.00148			
" 12, 1874.	50	60.5		0.00132			
" 14, 1874.	50	60.0			0.000563		
April 3, 1874.	100	121.2				0.000218	
" 10, 1874.	500	245.0		0.00140		0.000209	
" 27, 1874.	500	219.4				0.000157	0.000534
" 27, 1874.	600	340.0				0.000165	0.000538
Feb. 27, 1879.	1200	628.0				0.000179	0.000538
March 3, 1879.	1200	645.0	0.000153				
Mean, - - - - - - - -			0.000153	0.00140	0.000563	0.000186	0.000537

The determination of the numerical values of the constants A and F′ in Eq. (1) by sending successive charges through the coils of a Thomson galvanometer placed in the circuit designed for the fuzes, was an operation of extreme delicacy; but it was successfully accomplished with the efficient assistance of officers of the Battalion of Engineers. The galvanometer was a very good one, made by Elliott Bros., of London, and had a resistance of 5753 ohms at 19° Centigrade. For each adjustment of the weight on the movable arm of the electrometer, from ten to fifteen successive charges were sent through the galvanometer. The corresponding mean number of divisions passed over by the beam of light (corrected for the resistance of the air) was adopted, and is reported in the following table—which, therefore, includes the results of over 600 separate measurements. The observations were begun in each case at the zero of the electrometer scale,

and were continued up to the limit of the scale for measuring the swings of the beam of light. No shunt was used.

The figures in the columns of the following table headed "Computed swings", are those given by the formulæ deduced below; and attention is invited to the close accordance between them and the observations—which is also exhibited to the eye on the appended Plate. The columns headed "No condenser", exhibit measurements made to determine the charges due to the insulated surfaces of the apparatus with no condenser attached. The columns relating to the Leyden jar will be explained below.

OBSERVATIONS FOR CONDENSER CONSTANTS.

Electrom'r reading.	No condenser.			Condenser No. 1.			Condenser No. 2.			Jar and chain.			Jar and wire.		
	Obs. swing.	Comp. swing.	Diff.	Obs. swing.	Comp. swing.	Diff.	Obs. swing.	Comp. swing.	Diff.	Obs. swing.	Comp. swing.	Diff.	Obs. swing.	Comp. swing.	Diff.
$\frac{1}{100}$grs	divs.	divs.		divs.	divs.		divs.	divs.		divs.	divs.		divs.	divs.	
0	30	15	+15	71	65	+ 6	182	130	+52	25	29	− 4	361	295	+ 66
1				118	106	+12	204	212	− 8	122	116	+ 6	608	482	+126
2				148	135	+13	310	271	+39	183	211	−28			
3				158	159	− 1	323	319	+ 4	278	305	−27			
4				179	180	− 1	359	360	− 1	444	395	+49			
5				195	198	− 3	408	397	+11	544	481	+63			
6				196	215	−19	394	431	−37						
7				212	231	−19	456	463	− 7						
8				228	246	−18	465	493	−28						
9				258	260	− 2	508	520	−12						
10	64	64	0	257	273	−16	529	547	−18						
12				298	297	+ 1	595	596	− 1						
14				338	320	+18	644	642	+ 2						
15							657	663	− 6						
16				342	341	+ 1	693	684	+ 9						
17							706	705	+ 1						
18				357	361	− 4									
20	87	90	−3	343	380	−37									
25				430	424	+ 6									
30				480	464	+16									
35				516	500	+16									
40	129	126	+3	540	535	+ 5									
45				564	566	− 2									
50				594	596	− 2									
70	169	167	+2												
100	198	199	−1												
Sums.	677	661	24	6822	6852	218	7433	7433	236	1596	1537	177	969	777	192

The manner in which the formulæ were derived from these observations, is next to be considered. The discussion of the data for the apparatus without a condenser, and with condensers Nos. 1 and 2, offered no peculiar difficulty, and they will be treated first.

It is apparent that the constant F′ in Eq. (1) depends for its value upon the resistance offered by the inertia of the movable arm when exactly balanced. As this arm weighs only 32 grains, and is supported on two needle points, such a quantity is too small to be directly measured. It was thought best, therefore, to treat it as an unknown quantity in each case, and to adopt the mean of the three values resulting from the analysis. There are then two unknown constants, F′ and A (the latter for each condenser), to be determined from these observations.

Since the first member of Eq. (1) is directly proportional to the swings of the beam of light (S), it may be temporarily replaced by that quantity, A becoming $A_{,}$; giving:

(2) - - - - - - - - - - $S = A_{,} \sqrt{F + F'}$.

The first step was to deduce the most probable values for $A_{,}$ and F′ from the several recorded values of S and F. For this purpose, the equation was put under the following form, suitable for applying the method of least squares, $A_{,,}$ representing $\frac{1}{A_{,}^{2}}$:

$$S^{2} A_{,,} - F' - F = 0.$$

There are six equations of condition for the apparatus without a condenser, the last based on double the usual number of observations; twenty-two equations for condenser No. 1; and sixteen equations for No. 2. The following are the several normal equations, and the resulting values of the constants.

Without a Condenser.

$$4\,241\,437\,811 A_{,,} - 136\,175 F' - 10\,698\,050 = 0.$$
$$136\,175 A_{,,} - 7 F' - 340 = 0.$$
Hence: $A_{,} = 19.7.$
$F' = 1.09.$

Condenser No. 1.

$$552\,362\,376\,918 A_{,,} - 2\,613\,004 F' - 76\,328\,585 = 0.$$
$$2\,613\,054 A_{,,} - 22 F' - 361 = 0.$$
Hence: $A_{,} = 84.9.$
$F' = 0.11.$

Condenser No. 2.

$$1\,289\,004\,333\,943 A_{,,} - 3\,866\,911 F' - 43\,819\,136 = 0.$$
$$3\,866\,911 A_{,,} - 16 F' - 129 = 0.$$
Hence: $A_{,} = 167.4.$
$F' = 0.558.$

Remembering that the unit of the electrometer scale is one hundredth of a grain Troy, these three deduced values of F′ (1.09, 0.11 and 0.558) are sensibly the same quantity; and the mean, 0.6, was accordingly adopted. Substituting this value in Eq. (2), the corresponding values of A, were directly computed for each observation, and a mean of the results for each condenser was adopted; giving the following equations for the swing of the beam of light for any desired value of F.

(3). Without a condenser, - - $S = 19.8 \sqrt{F + 0.6}$.

(4). With condenser No. 1, - - $S = 83.8 \sqrt{F + 0.6}$.

(5). With condenser No. 2, - - $S = 167.9 \sqrt{F + 0.6}$.

The remarkable precision with which these formulæ represent the observations, already shown by the foregoing table, is also exhibited to the eye by the Plate; and the result of the analysis certainly leaves nothing to be desired. The next step is to translate the swings of the beam of light into microfarads.

Denote by Q the quantity of electricity, or the amount of the electric charge expressed in microfarads; by K, the capacity of the condenser, and by K,, the capacity of the insulated part of the electrometer apparatus, both expressed in microfarads; by P, the difference in electrical potential which causes the passage of the charge through its circuit, expressed in volts; and by B, a constant. Then, since the swing of the beam of light (S) is directly proportional to the charge traversing the galvanometer coils, we have for any condenser (detached from the apparatus.)

$$Q = KP = BS.$$

In this expression B is a constant for any particular setting of the magnet of the galvanometer; and its numerical value can be directly determined by observing the swing corresponding to any known values of K and P.

But immediately after the foregoing observations with each condenser had been completed, and before any change had been made in the position of the magnet of the galvanometer, observations were made to determine this value, accurately, by using the standard half-microfarad condenser charged successively by batteries of measured and widely different electromotive force. Thus:

For the setting used with condenser No. 1 (April 3, 1874):

$$B = \frac{0.5 \times 121.2}{28\,300} = 0.002141.$$

For the setting used with condenser No. 2 (April 27, 1874):

$$B = \frac{0.5 \times 219.4}{46\,200} = 0.002376.$$

$$B = \frac{0.5 \times 2.918}{628} = 0.002323.$$

$$B = \frac{0.5 \times 5.836}{1230} = 0.002372.$$

Mean value, 0.002357.

For the setting used with the insulated part of the apparatus (March 3, 1879):

$$B = \frac{0.5 \times 648}{164\,750} = 0.001966$$

$$B = \frac{0.5 \times 228}{57\,900} = 0.001969.$$

$$B = \frac{0.5 \times 415}{105\,500} = 0.001967.$$

$$B = \frac{0.5 \times 1.456}{370} = 0.001967.$$

Mean value, 0.001967.

All the data needful for transforming the equations for the swings of the beam of light, already deduced, into equations of which the units are microfarads and volts, have now been obtained. Thus, Eq. (2) becomes:

(6). - - - - - - $Q = (K + K_{,}) P = BS = BA_{,} \sqrt{F + F'}$.

And substituting the numerical values of B and $A_{,}$ and F', and reducing:

(7). Without a condenser, - - - $Q = K_{,}P = 0.03896 \sqrt{F + 0.6}$.

(8). With condenser No. 1, - - - $Q = (K + K_{,}) P = 0.1794 \sqrt{F + 0.6}$.

(9). With condenser No. 2, - - - $Q = (K + K_{,}) P = 0.3962 \sqrt{F + 0.6}$.

These equations express in microfarads the quantity of electricity sent through the circuit for any reading (F) of the scale of the electrometer; which, it will be remembered, is graduated in hundredths of a grain Troy. To transform them to express the difference of potential which causes the charge to traverse the circuit, it is only needful to substitute the numerical values of K and $K_{,}$, given in the table on page 247, and reduce. Thus:

(10). Without a condenser, - - $P = 254.7 \sqrt{F + 0.6}$.

(11). With condenser No. 1, - - $P = 529.1 \sqrt{F + 0.6}$.

(12). With condenser No. 2, - - $P = 552.9 \sqrt{F + 0.6}$.

The values of the coefficient of the radical in these equations illustrate the importance of using a condenser with my electrometer. It fulfills two objects; (1) it holds the charge bound, so that the loss during the instant which intervenes between the starting

of the movable arm and its closing the circuit is reduced to a minimum; (2) it tends to cause a uniform increase of the charge as received from the frictional machine, thus preventing the apparatus from acting by pulsations.

From the principle of the instrument, the size of the jar can have nothing to do with the potential which causes the discharge; i. e., the coefficient of the radical in these equations should be a constant. That the observations show it to be so, is evident from the values deduced with the three different condensers (the last to be subsequently explained); viz:

Condenser No. 1,	capacity	0.000186	coefficient 529.1
" " 2,	"	0.000537	" 552.9
Leyden jar	"	0.001400	" 528.7
Mean, - - - - - - - - - -			536.9

Adopting this mean, we have for the general potential equation applicable with any condenser:

(13). - - - - - - - - - $P = 536.9 \sqrt{F + 0.6}$.

A comparison of this equation with Eq. (10) exhibits the combined effect produced by the two causes above mentioned. Accordingly, the apparatus has never been used without a condenser, except in testing a few fuzes made with a priming so sensitive to electricity as almost to exceed belief. For them, the instrumental irregularities were fairly corrected by the manner in which Eq. (7) and Eq. (10) were deduced.

It is evident that Eq. (13) indicates a mode of severely testing the precision of the foregoing analyses; for when F is 0.4, P becomes 536.9 volts, and hence, if the poles of a battery having this electromotive force were connected with the two terminals of the apparatus, motion should take place. This experiment was tried with a battery having an electromotive force of about 630 volts, and the result verified the theory.

The Leyden jar, as already stated, was used in all the measurements prior to March 30, 1874, and occasionally afterward. Hence, to determine its equation accurately became a matter of importance; but a vexatious difficulty was encountered at the outset. As usual, the knob was connected with the inner coating of tin foil by a brass chain resting upon the latter. On attempting to measure the capacity, it was discovered that this contact was too imperfect to be passed by the voltaic current, and it was necessary to insert an elastic wire spiral before the work could be done. This mechanical detail was a matter of no importance; but when the charge was sent by the electrometer through the galvanometer, an extraordinary difference was developed between the two arrangements for the contact. With the chain, a large part of the smaller charges used

in these investigations remained in the jar, and did not traverse the external circuit at all! This is exhibited so plainly by the 11th and 14th columns of the table on page 248, that the fact requires no further demonstration. How to deduce a satisfactory correction did not at first sight appear easy.

The first step was to deduce a formula for the swing of the beam of light when the Leyden jar, with a good wire contact between its knob and inner coating, was used with the electrometer. An attempt to deduce this equation by direct trial failed, because the capacity was so large that observations could not be made when the electrometer reading exceeded unity; and even at zero and unity the motion was so excessive as to give results discordant among themselves. In other words, the galvanometer was too sensitive for the above method, with so large a condenser.

When the equations with condensers No. 1 and No. 2 were deduced, the position of the magnet had been made as closely as possible the same; and a comparison between the coefficients of the radical showed them to be nearly proportional to the capacity $(K + K_1)$. Thus, for $F = 0.4$, Eq. (4) becomes $S = 83.8$; and Eq. (5) $S = 167.9$. The ratio of these quantities is:

$$\frac{167.9}{83.8} = 2.004.$$

The ratio between the corresponding capacities is:

$$\frac{0.000537 + 0.000153}{0.000186 + 0.000153} = 2.035.$$

This verification of what theory would indicate, made it proper to compute the value of the coefficient of the radical in the equation for the swing of the beam of light with the Leyden jar, from the known capacities and from the coefficients for condensers No. 1 and No. 2. Thus, from the former it would be:

$$\frac{0.001400 + 0.000153}{0.000186 + 0.000153} \times 83.8 = 384.$$

And from the latter:

$$\frac{0.001400 + 0.000153}{0.000537 + 0.000153} \times 167.9 = 378.$$

The mean, or 381, was adopted, giving:

(14). With Leyden jar and wire, - - $S = 381\ \sqrt{F + 0.6}$.

This equation accords sufficiently well with the few direct observations to bring its indications within the limits of error due to magnet adjustment, as is shown by the table on page 248.

The corresponding value of B was assumed to be 0.002155, the mean of the three

measured values given above. Hence, for the quantity and potential equations of the apparatus, with the Leyden jar and a good wire contact between the knob and inner coating:

$$(15). \quad Q = (K + K_{,}) P = 0.821 \sqrt{F + 0.6.}$$

$$(16). \quad P = 528.7 \sqrt{F + 0.6.}$$

These equations compare well with those for the other condensers, and may safely be considered to apply to the few observations made when the wire was inserted in the jar. To deduce the more important formulæ for observations when the chain contact had been used, involved a troublesome analysis of the data, based upon the observed fact that the bad contact had, in effect, reduced the capacity of the jar. Without going into details, it is sufficient here to give the final results of this study.

$$(17). \quad S = \frac{\left(0.821 - \frac{3.965}{F + 5.357}\right) \sqrt{F + 0.6}}{0.002155}$$

$$(18). \quad Q = \left(0.821 - \frac{3.965}{F + 5.357}\right) \sqrt{F + 0.6}$$

A comparison of the indications of Eq. (17) with the observations, is exhibited in the table on page 248, and also shown to the eye on Plate XXI. The accordance is so close as to give confidence in the success of this analysis, which is fully borne out by comparative fuze tests with this and the other condensers.

This terminates the discussion of the constants of my fuze testing electrometer; and when it is remembered that many of the charges employed in deducing them were so small as to be quite inappreciable to the sense of touch, the study furnishes a beautiful illustration of the precision of the modern system of electrical measurement, rendered possible by the invention of Sir William Thomson's reflecting galvanometer. My apparatus proved to be by no means too delicate; for its most careful adjustments were needed in testing the large class of dangerously sensitive fuzes — now fortunately banished from our market, in part through its agency.

Theory of Ignition. The theory usually accepted for the ignition of high tension and medium tension fuzes, is that the heat generated by the passage of the spark through the priming raises the temperature sufficiently to produce explosion. This view rests entirely upon analogy, no attempt having been made to verify it by experimental research. Indeed, without suitable apparatus specially designed for the purpose no precise analysis of the problem would be possible.

Some classes of these fuzes are so excessively sensitive to electrical disturbance that,

for them at least, it is not easy to accept this theory. A person placed in the same circuit experiences no sensible shock from charges greatly exceeding the minimum required to explode them. An ebonite comb passed a few times through the hair of a child holding one of the terminal wires, the other being insulated in the air, generates a current quite sufficient to fire the priming. On one occasion at Willet's Point (July 15, 1871), fifty of these fuzes connected in series were hung upon nails driven in the sides of a wooden shed; and the induction of an ordinary thunder cloud caused the explosion of five of them — every fuze which touched a nail.

It seemed desirable to study experimentally the probable explanation of ignitions due to so slight apparent disturbances of electrical equilibrium; and, more generally, to investigate the laws governing the explosion of the two classes of fuzes now under consideration.

As already seen, the apparatus described above renders it easy to measure both the quantity of electricity Q, and the corresponding difference of potential P, which cause the explosion of a tension fuze; and also, by changing the condenser, to determine the effect of varying the numerical value of the potential factor. But Joule's law for the heat (H) generated by a current of electricity, of which the electromotive force is E, and the strength is C, traversing a circuit of which the resistance is R, in the time T, is:

$$H = C^2RT = QCR = QE = QP.$$

Hence, if the theory that the explosion is due directly to the rise in temperature caused by the heat developed by the passage of the spark be true, we must have the product QP nearly constant with different condensers.

Experiments were made to supply data for applying this test. Before considering them, however, it may be well to invite attention to one important difference between medium and high tension fuzes. The former oppose so small a resistance to the passage of the spark, that a relatively small difference of potential may safely be assumed to be sufficient to force the charge through the priming. With high tension fuzes, which oppose an enormous resistance, no such assumption is legitimate. Their primings constitute an absolute break of continuity in the circuit. This difference between the two classes is indicated to the the eye by the electroscope used with my electrometer. With medium tension fuzes and small potentials, the balls drop instantly; with high tension fuzes, up to a certain point, they fall gradually. Hence, with the latter class it is absolutely necessary to create a difference of potential sufficient to force the spark through the priming before explosion *can* occur. With a large condenser, this may imply a charge *larger than is absolutely needful to cause explosion*; and hence, for them the minimum charge can only be determined by using a small condenser with its relatively

large difference of potential. In other words, it is necessary with high tension fuzes, that the factor P in the product $(K+K_{,})\,P = Q$, shall be large enough to force the charge through the priming, before it can be considered certain that the minimum exploding charge has been determined.

Bearing this principle in mind, three different fuzes were selected for the trial—the Abel magnet fuze, as a fair sample of the medium tension class (resistance about 100 000 ohms when measured with six Leclanche cells); the Giant Powder Company fuze, as the representative of a rather sensitive high tension variety (resistance exceeding ten megohms); and the Browne No. 4, as a good type of a safe high tension fuze (resistance similar to last). The following table exhibits a summary of the results, each figure being the mean of from ten to twenty independent measurements which accorded well with each other.

TENSION FUZES—CONDITIONS OF IGNITION.

Fuzes tested.	Without Condenser.				With condenser No. 1.				With condenser No. 2.				With jar & chain.			
	Failed.		Exploded.		Failed.		Exploded.		Failed.		Exploded.		Failed.		Exploded.	
	Q.	P.	Q.	P.	Q.	P.	Q.	P.	Q.	P.	Q.	P.	Q.	P.	Q.	P.
	mf.	volts.	mf.	volts.	mf.	volts.	mf.	volts.	mf.	volts.	mf.	volts.	mf.	volts.	mf.	volts.
ABEL.																
1874.									1.36	1847	1.42	1917	1.11	1317	1.28	1422
1879.					0.99	2976	1.14	3411	1.07	1444	1.23	1671	0.87	1163	1.17	1376
Means.					0.99	2976	1.14	3411	1.22	1645	1.33	1794	0.99	1240	1.22	1399
G. P. Co.																
1879.	0.35	2274	0.38	2468	0.46	1372	0.52	1551	1.00	1354	1.10	1482	1.15	1321	1.33	1444
B. No. 4.																
1874.									1.79	2446	1.87	2542	2.24	1984	2.36	2057
1874.					1.92	5756	2.02	5989					2.25	1992	2.37	2063
1874.					1.62	4833	1.69	5066	1.95	2771	2.01	2873				
1879.					1.91	5106	1.98	5260	2.16	2930	2.32	3146	1.77	1712	2.07	1880
Means.					1.82	5232	1.90	5438	1.97	2716	2.07	2854	2.09	1896	2.27	2000

To exhibit these comparisons graphically, they have been translated into swings of the beam of light by the foregoing formulæ, and plotted in dotted lines on the Plate. For example, to explode the Abel fuze required 0.39 grains of repulsion with condenser No. 1; 0.09, with condenser No. 2; and 0.06, with the jar and chain—the corresponding swings with the galvanometer being in each case about 530 divisions.

Considering first the Abel fuze—which, since the question of potential can be ignored,

appears the most simple standard of comparison, these figures prove beyond cavil that the ignition depends upon the quantity and not upon the product of the quantity by the difference of potential. Thus for the grand mean, although the potential factor in the expression $(K+K_{,})P$ varied between 3411 and 1399 volts, the fuze always exploded when 1.25 ± 0.03 microfarads of electricity traversed the priming. Hence, since the second introduction of P as a multiplier would produce great discrepancies in the results shown by the three condensers, which without it are very accordant, the explosion *is not due directly to the rise in temperature caused by the heat generated by the passage of the spark, but to some other cause.*

The same conclusion, although at first sight less apparent, is reached by an analysis of the results with the other varieties.

Thus, the Giant Powder Company fuze, without a condenser, is exploded by the passage of a charge of 0.38 microfarads, with a difference of potential of 2468 volts—failing with 0.35 microfarads and 2274 volts. With condensers No. 1 and No. 2 and the Leyden jar, charges of 0.46 and 1.00 and 1.15 microfarads fail, because the corresponding differences of potential (1372, and 1354 and 1321 volts) are too low to force the charge through the priming. As soon as this difference reaches about 1450 volts, the charge passes and explosion results—with the condensers, *from an excessive charge.* Hence, the true minimum charge for this fuze is say 0.4 microfarads; but it cannot be fired with a difference of potential under about 1450 volts.

In the Browne No. 4 fuze, the break between the wire terminals in the priming chamber is considerably larger than in the Giant Powder Company fuze; and a difference of potential of about 2000 volts is apparently needful to force the charge through the priming. The quantity required with the three condensers is 1.90, 2.07 and 2.27 microfarads, respectively, with corresponding differences of potential of 5438, 2854 and 2000 volts. Evidently the minimum explosive charges, here also, are nearly proportional to the *quantity of electricity traversing the priming*—a small allowance being made for the modifying cause indicated above.

It will be noted that neither for medium nor high tension fuzes do the figures indicating ignition suggest any law based upon the product of the quantity by the difference of potential. On the contrary, they all imply that the ignition depends simply upon the *quantity of electricity traversing the priming.*

In fine, these experimental researches all seem to indicate that rise in temperature induced by the passage of the spark is not the true cause of the explosion of the primings of high and medium tension fuzes—at least, if we may assume that this rise is propor-

tional to the heat developed (QP). Even if this assumption be challenged, the difficulty is not met; for the advocate of the usual theory, in that case, must be prepared to admit that this rise is proportional to $\frac{H}{P}$, a law for which we have no warrant either from theory or from analogy.

In my judgment, these researches force us to seek the cause of the ignition in some occult law of molecular physics; and the following naturally suggests itself. May not the spark *polarize the planes* of the molecular orbits, as well as increase their amplitude? Prof. Henry, many years ago, proved that the passage of a spark of electricity among steel needles caused their permanent magnetization; which, by the theory of Ampère, would imply an analogous effect. In compounds where the chemical equilibrium is so unstable as in these primings, such a cause might well induce chemical action involving new combinations of the atoms — attended with explosion, or perhaps with a rise in temperature ample of itself alone to explain the phenomenon.

Since high tension fuzes require a spark for their ignition, this discussion covers the whole ground for them. Medium tension fuzes, however, may also be fired by the passage of a voltaic current through their priming; and this mode of ignition has been treated by Major Malcolm, R. E., in a very interesting paper read before the Society of Telegraph Engineers, in London, on May 13, 1874.

Major Malcolm discovered, by experiment, that a marked fall in resistance precedes explosion when caused by the passage of a voltaic current. He suggested that this change might continue with great rapidity during the instant just before ignition (in which it could not be followed by his instruments), and might thus explain the explosion by the heat generated by a current much stronger than the normal resistance of the fuze would imply.

This case is entirely different from ignition by a spark, and Major Malcolm's theory seems to me to be not only consistent with all the known facts, but also to receive confirmation from more recent investigations leading to the discovery of the microphone. With a voltaic or a continuous magneto-electric current, the element of time, which is inappreciable with the spark, becomes very important; and it is not hard to understand how a gradual and increasing rise in temperature quite sufficient to produce ignition may be brought about.

Standard of Safety. As already stated, many varieties of tension fuzes are so sensitive to electrical disturbance as to be criminally dangerous for practical use. Having adopted a system of measurement by which these fuzes could be accurately classified as

to sensitiveness, the next point was to decide upon an absolute standard of safety.

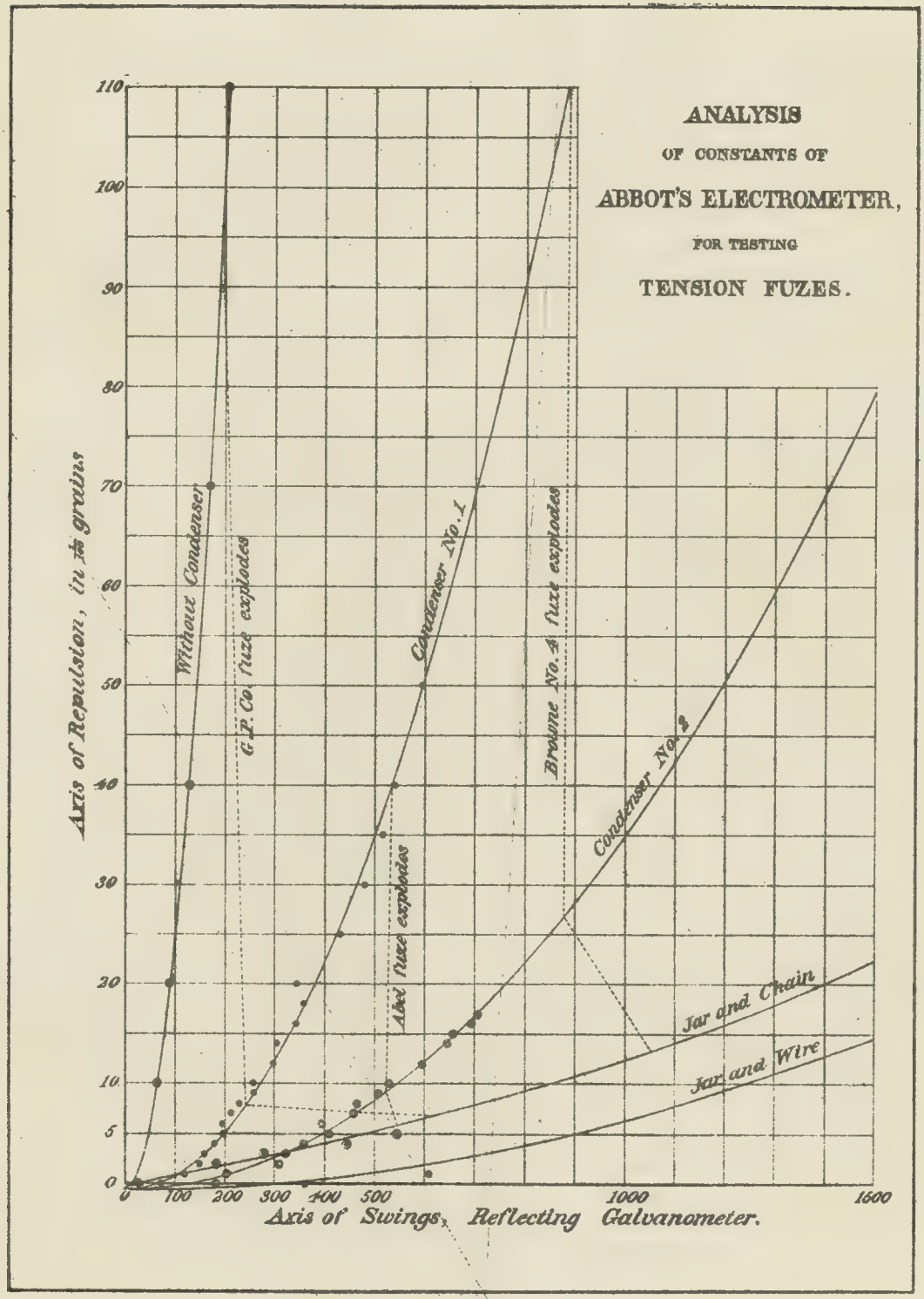
Whatever changes may be occurring in the electrical condition of bodies around us, we know by experience that none appreciable to our sense of touch are to be apprehended, under ordinary conditions. Hence, if no fuze which can be fired by a charge too small to be detected by this sense be employed, the condition of reasonable safety may be regarded as fulfilled. On the other hand, this limit should not be largely exceeded; because it is often desirable to fire several charges simultaneously, and if the fuzes be too hard to ignite, miss fires with loss of time and dangerous manipulations are sure to occur.

To fix the numerical value of this standard, a man holding the wire terminals in his moistened hands replaced the fuze in the electrometer circuit, and the reading corresponding to the smallest sensible shock was noted. Some individuals proved to be more sensitive than others, but the following record may be considered a fair average.

Without a condenser, a shock corresponding to a reading of 180 could not be felt; with condenser No. 1 a reading of 8 could not be felt, and of 10 could be just detected; with condenser No. 2, these numbers were 2 and 3 respectively. Translated into microfarads, these results may be tabulated as follows:

Without a condenser,	0.52	mf.	could	not	be	felt;								
With condenser No. 1.,	0.64	"	"	"	"	"	0.75	mf.	could	be	just	detected.		
" " No, 2,	0.53	"	"	"	"	"	0.58	"	"	"	"	"		
Means,	0.56						0.67							

From these figures, it appears that no fuze which can be fired with a less charge than about seven-tenths of a microfarad can be regarded as a safe fuze. Eight-tenths of a microfarad is distinctly felt by any person, and this was adopted as the minimum standard. As to a maximum, a thoroughly good fuze not liable to deteriorate by age and exposure to dampness, and which requires about two microfarads for ignition, was discovered; and this charge was accordingly adopted as the standard. It gives a decided but not disagreeable shock. The charges required for igniting the different primings subjected to trial, have ranged between 0.03 and 16.00 microfarads.


ANALYSIS
OF CONSTANTS OF
ABBOT'S ELECTROMETER,
FOR TESTING
TENSION FUZES.
Axis of Repulsion, in ⅛ grains
Axis of Swings, Reflecting Galvanometer.
Without Condenser
G.P. Co. fuze explodes
Condenser No. 1
Browne No. 4 fuze explodes
Abel fuze explodes
Condenser No. 2
Jar and Chain
Jar and Wire
110
100
90
80
70
60
50
40
30
20
10
5
0
0
100
200
300
400
500
1000
1500

NOTES

ON

MAYER'S MAGNETOMETER.

READ BEFORE THE ESSAYONS CLUB OF THE CORPS OF ENGINEERS,

OCTOBER 27, 1879;

BY

WILLIAM S. HEGER,
MECHANICAL ENGINEER.

NO. XLVIII. PRINTED PAPERS.

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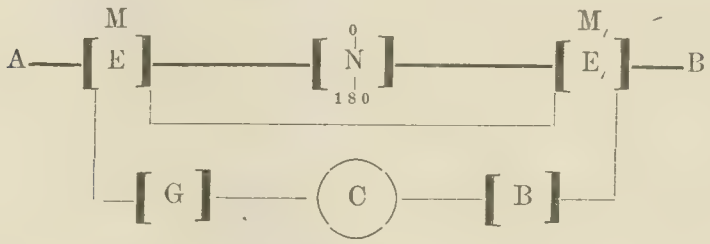
MAYER'S MAGNETOMETER.

A paper read before the "ESSAYONS CLUB" of the Corps of Engineers, on October 27th, 1879, by W. S. Heger, M. E.

Having to investigate a new method of winding the helices of electro-magnets, I made use of an apparatus designed by Prof. Mayer, of Stevens Institute of Technology, for measurements of this kind.

The accuracy of this apparatus combined with simplicity of construction, renders it a valuable accessory to the physical laboratory, and I now lay a description of the same before you, together with a résumé of the above mentioned investigation.

DESCRIPTION OF MAGNETOMETER.



On a beam A B, 10 feet long, was drawn a centre line divided into tenths of inches from its middle. On each side of this line ran guides parallel with it, on which were mounted three stages M, M, and N. N was stationary, being fastened to the centre of the beam and carrying a sensitive needle 12 inches long, which played over a circle divided to tenths of a degree.

The point of suspension of the needle was over the middle of the centre line, and the line 0—180° of the divided circle, was so placed, as to make an angle of 90° with the centre line at that point.

The stages M and M, were provided with verniers to read to the $\frac{1}{100}$ of an inch,

and carried two electro magnets E and $E_{/}$. These were placed in such a manner, that the like poles faced the needle, and that a line drawn through the point of suspension of the needle parallel to the centre line of the beam, would form the axis of their cores.

The poles of these electro-magnets were also placed accurately over the zero of the verniers.

The connections were made as shown in the diagram; E and $E_{/}$ being the electro-magnets, B the battery, C a commutator for reversing the current, and G a tangent galvanometer placed at a sufficient distance not to be effected by the magnets E and $E_{/}$. The lead wires were also so arranged as not to act by induction on the magnetic needle N. This should be ascertained after the connections are made by cutting out the electro-magnets and closing the circuit through the lead wires alone.

Observing the action of this apparatus, we see that when the current is passed through the electro magnets, the needle N is subjected to the powerful action of two opposing forces. A magnetic couple is formed whose equilibrium, shown by the needle, is readily disturbed by a change in the relative forces of the cores, or by a change in the distance of the needle relatively to the two helices.

Changes of the current do not affect the needle, as both cores are subjected to the same changes; but a movement of $\frac{1}{100}$ of an inch of one of the cores, to or from the needle, will cause a deflection of several degrees.

In using this apparatus the centre line of the beam must be placed at right angles to the magnetic meridian, or in other words, the needle must be brought to zero.

The law of variation of the intensity of action of the electro magnes on the needle with a change in its distance from the magnetized core, varies slightly with the construction of the apparatus and can be easily determined by experiment.

This law ascertained, we will have a system of measurement for the electro magnetic forces which will exceed in accuracy and in delicacy the best photometric processes, to which in its arrangements it is similar.

This apparatus I made use of in investigating the claims made by M. Ernest Bisson, in a paper read before the French Academy of Sciences. An abstract of this paper is published in the *Comptes Rendus*, and contains a claim of the inventor, of an advantage of a third in the power of an electro magnet, which is wound according to his new method. This new method consists in winding the first layer in the usual manner; but, instead of commencing the second layer where the first ends, the wire is carried back in a straight line to the starting point, and the second layer wound in the same direction as the first. This is done for each layer till the helix is finished.

Brisson states that with the same core, the same battery and the same amount of

wire, he obtained an electro-magnet one third stronger with the bobbins wound in accordance with his new method.

The set of experiments I conducted to verify this result were carefully made and especial care taken to have the helices exactly alike in all but the manner of winding.

I used two sets of helices. The first two were wound with 95 feet of No. 16 wire in four layers, each having the same number of turns to the layer, and the layers being the same distance from the core in each. These helices when finished were $4\frac{1}{2}$ inches long; one being wound in the usual manner and the second according to the new method.

The second two helices were each 9 inches long, wound with 300 feet of No. 16 wire, in 6 layers, also both alike except in the manner of winding.

In order to get the layers of wire in both methods the same distance from the core, a piece of cardboard a little thicker than the wire and measuring a trifle less than the circumference of the helix was taken. This was bent around each layer, thus forming a cylinder with a longitudinal slit, in which the wire could be carried back to the starting point and still preserve a smooth surface for the next layer to be wound on. In the common method of winding, this cardboard cylinder was also placed between each layer, thus giving them respectively the same distance from the core.

The two cores used were of the same iron and exactly of the same size in each set. They were $10\frac{1}{2}$ inches long and $1\frac{1}{16}$ inches in diameter. They were so placed in the helix that they projected equally at each end. In the first place the core projected 3 inches and in the second $\frac{3}{4}$ inch. In making the tests care was taken always to present the same face of the core to the needle.

As all the measurements were made from the pole of the electro-magnet, it became necessary to fix the position of this exactly; also to see what effect the different lengths of projecting core would have on it. In the case of the end of the core being in a plane with the end of the helix, the pole would be in this plane; but for a projection of three inches, the pole was in the axis of the bar $1\frac{3}{8}$ inches from this plane. For the projection of core of $\frac{3}{4}$ inches, it was $\frac{1}{8}$ of an inch distant.

In ascertaining the position of the pole I used one of Prof. Mayer's floating magnets. A fine sewing needle was inserted in a piece of cork in such a manner as to float in a vertical position; it was then magnetized so that the upper end had the opposite polarity to the pole in question. This little piece of apparatus was floated in a vessel of water over which the electro-magnet was suspended, and on the closing of the circuit took its position vertically under the axis of the core at the above mentioned distances from the plane of the helix. On being removed, the needle would always return to the

same place, showing that vertically above it, in the axis of the core, was the point of strongest attraction or the pole of the electro-magnet.

On commencing the experiments, the electro-magnets were so placed, that their poles were 4 feet 3 inches from the centre of the magnetic needle; they were then moved equally nearer, as far as the apparatus would allow, which gave a smallest distance of 8 inches. At these different distances the current of 1 to 8 gravity, and also of two large bichromate cells, was passed through the helices, all with the same result; the needle did not move.

The same was done with each set of helices; in each case the cores being interchanged, and the trial being made also without cores with the helices alone.

For each position the core was brought accurately to the division of the centre line before the current was closed, the difference of $\frac{1}{100}$ of an inch in the distance of the cores causing a deflection of several degrees. At the distance of 8 inches, a difference of this kind threw the needle around 50°—60° degrees.

To avoid saturation, the trial was repeated with one cell gravity, in each case with the same result. In all the above trials the needle remained stationary, showing the helices to be equal in strength.

To verify the above, I constructed a magnetometer, using as an armature a wrought iron ball. This ball was suspended from one arm of a balance and in contact with the core. This latter was placed with its helix in a vertical position below the point of suspension of the ball. The current was closed through the helix and the opposite arm of the balance weighted till the ball was torn off. The first helix was now replaced by the second, and the experiment repeated. This was done several times for each helix; mean of the weights necessary to draw the ball off was found to be equal for each helix.

The results of both magnetometers showed a perfect equality of the two methods of winding in their effect on the core. In the test with the first magnetometer at a distance of only 8 inches from the needle, and the helices traversed by the current of 2 large bichromate cells, the needle remained perfectly stationary as long as the distances were exact.

This severe test shows plainly that there could be no difference in the strength of the two magnets; and, as both were exactly alike except in the mode of winding, the conclusion is easily deduced, that this new method of winding does not fulfil that which is claimed for it, and that it must be ranked among the many futile attempts at finding a better method of winding the helices of electro-magnets.

APPLICATIONS

OF

PHOTOGRAPHY IN WAR.

READ BEFORE THE ESSAYONS CLUB OF THE CORPS OF ENGINEERS,

APRIL 26, 1881;

BY

CAPTAIN JAMES B. QUINN,
CORPS OF ENGINEERS, U. S. A.

NO. XLIX. PRINTED PAPERS.

Printed on the Battalion Press.
Sergt. Carmichael and Pvt. Beck, Printers.

APPLICATION OF PHOTOGRAPHY TO MILITARY PURPOSES.

A paper read before the "ESSAYONS CLUB" of the Corps of Engineers, on April 26, 1881, by Capt. James B. Quinn, Corps of Engineers.

The photographic art owes much to the early discoveries of an officer of the French army. Whatever his speculations concerning the future of the art may have been, it is quite likely that his most enthusiastic and extravagant expectations have been more than realized in the present extensive application of his discovery to warlike purposes. There is probably not a department in the military establishment of any civilized nation, which does not make more or less use of photography for the copying of maps, the reproduction of designs, the explanation of service patterns, the illustration of reports of operations on public works and on surveys and explorations of public lands, the recording of experimental results, the instruction of troops, and for other purposes too numerous to mention—the faithfulness of the results secured by aid of the art causing its application wherever its services can be made available.

The inexpensiveness of the process and the facility with which results may be obtained, give to photography a peculiar value aside from its advantages on the score of fidelity; and in many cases where it would have been impossible to secure pictures by other means, its results are simply priceless.

The first application of photography to military operations in the field occurred in 1855-6, in the Crimean War. This work was carried out by some English officers specially instructed for the purpose; and some very creditable results were obtained—the views being very interesting and instructive, and clearly indicating the importance of further undertakings of this kind.

During recent years photography has made indeed wonderful progress, its applications having correspondingly increased and become more widespread. In its successful application, therefore, a more extensive knowledge of the art becomes necessary, and particularly is this the case in military matters, where considerable diversity of uses

occurs. Consequently, in England and the principal Continental nations, extensive and very complete establishments are maintained by the Departments of War, where young soldiers are instructed in the different manipulations of the process and specially trained for this particular service in the field.

During our late war, the Chiefs of Engineers, appreciating the value of photography, caused portable outfits to be prepared, and very extensively used throughout the armies—each division having a photographer attached for performing special duties in time of need. It does not appear that beyond the multiplication of maps and sketches of the enemy's country, any great use of photography was made; but in this limited application, however, it proved exceedingly valuable—the maps prepared in this manner being widely used for the planning of campaigns, raids, expeditions, etc. Gen. Sherman, previous to his departure from Atlanta, caused photographic copies of all the maps relating to the proposed route to be made and distributed throughout his command; and throughout the war there were many occasions during the periods preceding a fight when much valuable time was saved by employing the camera in the preparation of the necessary sketches for distribution to the corps and division commanders.

The Medical Department of the Army, during the late war, made much use of photography for the accumulation of valuable information, remarkable cases of gun-shot wounds, amputations, successful surgical operations, etc. The different arrangements employed in transporting and caring for the wounded on the field, and the distribution and duties of attendants to give the greatest efficiency under such circumstances, were photographed; and in the event of another war, there can be no question but that the study of these photographs will be instrumental in a great degree in ameliorating the sufferings of the sick and wounded, by indicating to the medical officers studying them the proper course to pursue or expedient to adopt under similar circumstances.

The Quartermaster Department avails itself of the services of the camera to indicate the precise manner in which the harness of horses is adjusted, the fitting of service saddles effected, the method of packing wagons performed, the manner in which tents and cantonments are set up, and in illustrating the manner in which the trimmings and ornaments are applied to the uniform, etc.

The Ordnance Department makes use of photography in describing the different kinds of guns, carriages, implements, ammunition, etc, and in recording the results of experimental firings; in explaining the different methods of mounting and manœuvering guns and inspecting ordnance materials; also in describing the methods of manufacturing and wearing the different accoutrements, and in preparing and preserving working drawings of the different ordnance stores and materials.

Some allusion has been made as to the manner in which the Engineer Department makes use of photography in the preparation of maps and sketches of the enemy's country; in addition to this, however, no exploration party equipped by it is considered complete without having a photographer attached. Much valuable information as to the character and peculiarities of the country explored has been thus obtained, which would otherwise have been inaccessable.

Reports of progress upon works of fortification, and experiments with shields and different defensive projects, are usually accompanied by descriptive photographs which give in the most intelligible manner the precise condition of the works or results of the experiments; and the same practice prevails with reference to those works of a civil character. During the investigations upon submarine mines, much valuable information was obtained by photographing the jets produced by different explosions; the several phases through which this exhibition of the explosive force passed were thus recorded with a completeness that by other means would have been unattainable. Furthermore, in connection with this subject of submarine mines, extensive use has been made of photography for illustrating the different portions of the system and the apparatus used in connection therewith—numbers of these descriptive charts being now stored and ready for issue.

Without dwelling longer upon the extensive use which has been made of the camera by the different military departments, I will pass at once to the consideration of the ways in which photography has been and may be used in connection with campaign service.

As has been previously intimated, the reduction and multiplication of maps and plans was considered throughout the late war, as by far the most important use to which photography could be applied in the field by the Engineers—the taking of views being rather relegated to the civilian photographer, if such happened to be accompanying the forces.

I do not think that the production of maps is the only important use that can be made of photography in the field; for, during the progress of an army through strange lands, it is of the greatest importance that the Commander in Chief should possess a perfect knowledge of the country surrounding him. Not only is an understanding of the position of the rivers, roads, mountains, etc., such as is shown upon ordinary maps requisite, but also an appreciation of the minor details, such as the character of the country, the condition of the roads, the whereabouts of timber, the location and condition of bridges, and other important features of like character. The camera is certainly without a rival when such information is required, both on account of the ease with which it may be used, and the confidence which may be reposed in its results.

The views need not necessarily be large to give all the needful details, since it is

advisable at all times to examine such views with a magnifying glass, as a certain degree of relief or stereoscopic effect is thus gained and the details are better understood. Such views could be appended to the reconnaissance maps supplied to the command; and since they would at a glance convey intelligible information respecting the country covered by the reconnaissance, the value of such maps would thereby be greatly enhanced. The time and trouble involved in obtaining such pictures would scarcely be appreciable, and no especial knowledge of the manipulations of the process would be required. The officer making the reconnaissance would be supplied with a small camera and a number of dry plate shields, the whole of which might be so arranged as to occupy a space not exceeding six inches cube. As the camera would generally never be very near the object to be taken, it might be provided with an ordinary lense so adjusted as to be in focus for objects not less than 100 times its principal focal distance, in as much as it has been found that a lense so focussed gives a tolerably clear definition of objects beyond the distance mentioned. No focussing would therefore, be necessary. The instrument would simply be put down on whatever support might be convenient, as a wall, stump, fence, or a light staff carried for the purpose, and pointed at the object to be taken by means of simple sights affixed to it, the dry plate inserted, and the exposure of the glass for a period depending upon circumstances made; the dry plate holder would then be removed and the apparatus returned to its case. Certainly no very great amount of instruction or practice would be necessary to familiarize any officer of ordinary intelligence with an operation so simple; a few minutes' instruction would probably be sufficient in any case.

On returning to camp, the plates would be handed over to the photographic staff, with suitable memoranda as to time of exposure and location of view; the remaining operations would be performed by the photographers in the usual manner.

These small pictures would be used in illustration of the reconnaissance maps, and with proper descriptions would be attached at suitable places upon the margins. If they should be required in large quantities, the Artotype process will supply them with almost any degree of rapidity; and if any of the views are of such importance as to require special inspection by the General commanding, enlarged prints could be prepared by means of the solar camera, or transparencies might be prepared and exhibited by means of the stereopticon or port lumière in a most satisfactory manner.

If positions of the enemy are to be reconnoitred which do not permit of sufficient nearness of approach to secure necessary details, a small camera can be readily affixed to an astronomical telescope and views obtained, which, if they do not possess great breadth of field, will give with distinctness such details as could only otherwise be obtained by an approach to $\frac{1}{4}$ or $\frac{1}{5}$ of the distance; furthermore, if this telescopic camera is provided

with a graduated circle for reading horizontal angles, the views obtained in this manner from stations at the extremities of a base line could be used for plotting the position of the different objects pictured, after the manner recommended by Captain Jouart and adopted to some extent by the French War Department. Without much risk or danger, serviceable views could thus be obtained of an enemy's works and the number of guns, location of embrasures, position of obstructions, and other features determined in a safe and satisfactory manner.

There are certain views of important positions which become possessed of historical interest in consequence of the operations of a campaign. It is to be regretted that, up to the present time, scarcely any views of this character have been taken by the military photographers—such not being considered as within their official duties. Some attention should be given to work of this kind during future military operations; and since printing in half tone by mechanical processes has been so wonderfully improved, there does not appear to be any excuse for not having reports of battles and sieges profusely illustrated by views taken from a military standpoint. Aside from the comprehensiveness of such reports, the views would show precisely the position of affairs; and the commanding officer, or the authorities at home, would rest assured of the accuracy of the representations, and be convinced that the same were not overdrawn or exaggerated.

It is not an uncommon thing for extensive civil engineering operations to be largely directed through the information supplied by photographic reports, and money advances agreed upon have been made upon the photographic evidences of the progress of the work. Works have been even successfully carried on in this manner in countries where for some reason the contractors were prevented from taking up their residence—the faithful representations of the camera in such cases supplying information that otherwise could be gained only by actual personal supervision.

Hitherto, it has been the practice to take the reconnaissance maps made by the officers on such duty, and copy them, after reduction to a uniform scale, upon a consolidated map. As this map was constantly subject to corrections as the reconnaissances were extended or repeated, it was usually left without inking in the lines. Tracings in ink of such portions as were required were made from time to time, and when several copies were required for distribution, a paper negative was obtained from the tracing and the maps printed from it; or else the tracing was used directly as the negative, in which latter case the lines would appear white upon a dark ground.

Some loss of time necessarily ensues from the necessity of reducing the reconnaissance maps to the same scale and then plotting them upon the consolidated map. This work could be much more rapidly performed by the aid of the camera; and if any large

number of copies of any particular reconnaissance were required, the glass negatives might be rapidly duplicated and the printing facilitated; or else photo-lithography might be resorted to, and the printing of maps be wonderfully expedited.

Concerning the choice of these several methods, much will depend upon circumstances. When a large number of maps are required, there can be no question as to the advisability of resorting to photo-lithography; it is only when there are a few copies required that there is any uncertainty. When expedition is involved, it is advisable to prepare glass negatives of the maps, if such do not already exist and a photograph with a dark ground is objectionable. Since the preparation of a paper negative consumes much time, and furthermore, as the paper is quite opaque and not transparent in the lines like a glass negative, the production of the maps by its use is a slow operation, even in a strong light. In fact, it is a saving of time, and but very little if any more trouble, to make a glass negative, prepare a photo-lithographic transfer, and lithograph the few maps required.

Maps for campaign purposes, when printed upon paper, should be mounted upon muslin; when lithographed, however, it is advisable to print them directly upon the muslin, as they are much more serviceable and convenient when prepared in this way.

The fact that lithographic stones are cumbersome and difficult to transport safely, would appear to present an important obstacle to the successful application of this method of producing maps in the field; but it is found that zinc plates with a grained surface, produced by the sand blast or other means, answer as well as stone, and are for military purposes much to be preferred, since their transportation presents no difficulties.

The question of transportation affects the entire subject of photography in the field, and gives to the dry plate process an important advantage, since the cumbersome dark tent, silver bath, and bottles of solution are in a great measure dispensed with. The dry plates occupy but little space, are always ready for use, and for certainty or uniformity of results are not to be excelled. With the wet plate process, the field photographer is constantly beset with difficulties which not only require considerable experience and sound theoretical knowledge, but the exercise of much skill and unlimited patience to overcome. The bath is continually getting out of order, and frequently is so on critical occasions; the collodions are subject to considerable variation, due to the alternations of temperature and other causes incident to working in the open air; and then the plate must be exposed and developed before the solutions dry upon it. With dry plates the necessity for immediate development does not exist; the plate may be exposed in the camera and then withdrawn—the development being postponed until a more favorable opportunity presents, an advantage which will be readily appreciated.

Among the different kinds of dry plates suitable for military use, gelatine bromide

emulsion plates from their exquisite sensitiveness and easy manipulation are perhaps most worthy of choice. They are manufactured in large quantities, and by recent formulæ are not so difficult to prepare as was at first believed.

Collodio-bromide emulsion plates are nearly as good, and are also to be had ready made in any desired quantity. If for any reason the ready prepared plates are not desired, the emulsion can be obtained separately, and the plates can be prepared as required with but very little trouble.

The ordinary wet plate may also be transformed into a very fair dry plate by washing out the soluble salts remaining in the film after sensitizing in the silver bath, then filling the pores with some uncrystallizable substance, called a preserver, and drying thoroughly; after which the plate is ready for use. The tendency of the ordinary silver bath to get out of order at unexpected times, is not calculated to invest plates prepared in this manner with much trustworthiness. In fact, it may be accepted as certain that for the ordinary usages of a campaign, the wet plate will have little or no application.

For the preparation of dry plates in the field, the collodio-bromide emulsion is most convenient, and for photo-lithographic work is unequaled; but the dry plate is not so sensitive as the gelatine plate, and for taking views in localities where the greatest expedition is essential, the gelatine plate—which requires but an instantaneous exposure—is therefore superior. The gelatine plate could not, however, be prepared with any certainty in the field, although the emulsion may be obtained separately, as in the case of the collodio-bromide. But for the taking of views it is doubtful if under any circumstances there would be any great necessity for attempting the manufacture of dry plates in the field, since the ready prepared plates could be transported with less difficulty than the materials in separate packages for making them. In photo-lithography, on the contrary, considerable saving may be effected by using again the glass of those negatives which are no longer required; and, therefore, it is necessary to keep on hand a supply of the collodio-bromide emulsion with which to coat such plates anew.

It is not to be understood that the general use of the dry plate in the field will so simplify photographic operations as to entirely obviate the necessity of any special training in the methods of its working, or in the degree of intelligence required for its judicious application. The development of the plate after exposure is not entirely mechanical, but requires the exercise of considerable judgment; and the same is true of every subsequent process, to the completion of the finished print. The mishaps and unforeseen dilemmas which encounter the operator at home are by no means few or unimportant; but when his work has to be carried on without the usual appliances, and recourse has frequently to be had to makeshifts, misfortunes are sure to arise which require the exercise of considerable skill and patience.

Good photographs are not merely the result of mechanical operations, but are dependent also upon the skill and judgment of the operator, as may readily be proved by an inspection of some of the views by the leading photographers. Hence, a responsible person should have charge of the photographic department in the field, and it is for several reasons necessary that he be a commissioned officer. The duty is essentially a military one; the requirements of the service must be understood and appreciated; certain information must be carefully guarded; the interference with the operators by staff officers unacquainted with the exigencies of the art must be controlled, and the administration of the service be so conducted as to secure the greatest possible efficiency.

Such direction would insure a constant attention on the part of the operators to their legitimate duties, and orders would consequently be attended to with certainty and dispatch. Furthermore, some good results from a military point of view might be expected which could hardly be attainable by any other means.

In thus presenting in a rough manner some of the many ways in which field photography may be made to facilitate the work of the Engineer Officer, I have not considered it essential to enter into the minutiæ of details concerning the operations hinted at, though at the same time I am aware that a practical understanding of such matters is of the greatest importance to enable one to direct such work intelligently. Yet, if I shall have succeeded in directing the attention of military minds to the study of this useful and beautiful art, or been instrumental in indicating the direction in which improvement in its application to military purposes may be expected or attained, I shall feel that my endeavors have been amply rewarded.

THE SUSPENSION BRIDGE

BETWEEN

NEW YORK AND BROOKLYN.

READ BEFORE THE ESSAYONS CLUB OF THE CORPS OF ENGINEERS,

FEBRUARY 22, 1882,

BY

1ST LIEUT. FRED. V. ABBOT,
CORPS OF ENGINEERS, U. S. A.

NO. L. PRINTED PAPERS.

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THE EAST RIVER BRIDGE.

A paper read before the "ESSAYONS CLUB" of the Corps of Engineers, on February 22, 1882, by 1st Lieut. Fred. V. Abbot, Corps of Engineers.

Through the kindness of Mr. Arthur V. Abbott, Assistant Engineer on the Brooklyn bridge, I have been enabled to thoroughly inspect this structure as it now stands, and to obtain copies of the reports of the Engineer in charge, with photographs taken at different times during the work. The reports are now out of print, and it is difficult to find copies of them anywhere; I have, therefore, combined in the following paper such information derived from them as seemed to me to be of special interest to our officers, with other facts which I have been able to gather by conversing with Mr. Abbott.

The plans of the bridge engineers were examined and reported upon by a board composed of General H. G. Wright, General John Newton, and Major W. R. King, all of the Corps of Engineers. This board approved the plans, and after an interesting discussion of the question: "Will the bridge, as designed, be an obstruction to navigation?" replied in the negative. This report is to be found on p. 397, Report of the Chief of Engineers U. S. Army, for 1869.

In arranging the subjects I have touched upon, I have generally followed the chronological order in which they became of primary importance in the bridge construction.

FOUNDATIONS.

The first matter to be decided upon was the manner of preparing the foundations. The two anchorages were so situated that but little excavation was needed to make them perfectly stable; but such was not the case with the towers. Their weight, increased by the load they would have to support when the bridge was completed, made it apparent that bed rock or a thick stratum of hard gravel must be reached before the work of excavation was stopped. The plan adopted was, as is well known, to sink a huge grillage constructed in the most substantial manner; the pneumatic method was employed, and the chamber was filled with concrete when the final resting place had been reached.

BROOKLYN CAISSON.

Work began on the Brooklyn side. The caisson, built by Messrs. Wett and Bell, is accurately described in most recent works on civil engineering; I therefore give no description. Two sections, fig. 1 longitudinal and fig. 2 transverse, both through a water shaft, are given. The dimensions may be found in the tables at the end of this paper.

Preparation of site. While the caisson was building a rectangular basin with sides formed of sheet piling was prepared for its reception. The face next the channel was of course left open till after the caisson was in the position where it was to be sunk. The depth required to float the caisson was only 18 feet at high tide, but the nature of the bottom caused much expense and delay in obtaining even this depth. On the eastern side of the basin soft clay easily dredged was found; in the centre a ridge of hard pan; on the south bowlders; and on the river side a perfect rip-rap of large bowlders. Logs, stumps of piles, and piles in position were thickly strewn all over the bottom.

In places the ground was so hard that iron piles were driven in a few feet, then drawn out, the holes thus left, charged and regular blasts resorted to. A large force of submarine divers, and very powerful dredging apparatus had to be employed.

On March 19, 1870, the unwieldy craft weighing 3000 tons was launched. In spite of the novel character of the operation, and the vast weight to be set in motion and guided, all worked satisfactorily.

On May 2nd it was towed to the basin, and hauled into place; when once in position it was securely held by a row of sheet piles driven on the fourth side of the rectangle, and all was ready to make the connections with the air pumps and start work.

Work in air chamber. By May 10th all was ready, and on that day air was forced into the chamber, and men entered. A serious difficulty at once presented itself, the caisson rose at high tide and settled at low, and this was liable to strain it and cause air leaks. The load increased rapidly but in place of improving matters it made them a great deal worse. The caisson would no longer float, but one end would stay on bottom, and the other rise, and this action did not take place gradually and regularly, but by jumps of six inches or more at a time.

Whenever this occurred air would burst out under the shoe with a loud noise, throwing up columns of water which are stated to have been sixty feet in height. Even after the caisson grounded so solidly that it did not rise at high tide these "blows" occurred. At high tide a greater pressure was required to keep the water out, than at low. The pressure should have been decreased again as soon as the tide began to fall, but it is not an easy matter to regulate the tension of 175000 cubic feet of air exactly, the result was

that it would soon be greater than that needed to sustain the external column of water, and as before a great rush of air under the shoe followed. This was always the cause of a very dense fog in the caisson, which would obscure everything; as soon as the air ceased to rush out, water poured in from all sides flooding the bottom to the depth of a foot or more. This peculiarity rendered work in the air chamber decidedly unattractive.

"Blows" were sometimes caused by the swells of passing steamers, but occurred most frequently from the fall of the tide. It was a curious fact that those inside felt the effect of blows very little, except in the indirect way before described. The volume, 175000 cubic feet, was so great as compared with any volume that could escape in two or three minutes, which was about the time a blow usually lasted, that the pressure was not sufficiently decreased to make it perceptible to the senses.

The caisson was not allowed to rest on the shoe, but was supported by the heavy frames dividing the air chamber into six compartments. Under each of these frames a trench about two feet deep was dug; on the bottom of these trenches temporary pillars, composed of two blocks of yeliow pine $12'' \times 12'' \times 20''$, with their larger axes horizontal and parallel to the direction of the frames were constructed at distances of 8 feet. Between the upper block, and the caisson frame four thick wedges were inserted. A free space for about six inches was now cleared out under the shoe, all round the caisson, the wedges were then loosened by sledge hammers, one by one and frame by frame, until the caisson had settled slowly, and the frames were bearing directly on the upper blocks of the pillars. The trench was now deepened and new pillars erected alongside those supporting the caisson; they were brought to a bearing by driving in wedges with sledges. The old pillars were now undermined and removed, and the operations repeated in the same order as before. Frequently a sudden descent of the caisson would crush half of the bearing blocks, before it was brought up by the shoe. The noise in the air chamber at such times is said to have been very trying to the nerves of those who appreciated the immense weight which was above them.

At the outset the whole bottom was submerged, and the hard earth had to be removed by long handled shovels after it had been loosened by driving steel pointed crow-bars down a foot or so with sledges. Picks were tried but found to be almost useless when used under water.

After the caisson had sunk two feet it was found possible to build dams round the frame trenches and bail them out. This made the labor of deepening them much less. Several pumps and siphons were tried, but the most efficient was found to be a simple suction hose, communicating with the external air. By holding the end so that only a part of the orifice was submerged in the water of the trench, and opening a valve, the

air rushed through the unsubmerged portion of the orifice so violently, as to carry both mud and water up with it. By its use the trenches were bailed out promptly and well. Care was taken to always leave one trench filled with water which was in communication with the outside, that the water shaft should be kept supplied.

The earth in the compartments between the trenches was removed by digging as fast as it was left above water by the sinking of the caisson.

But little difficulty was met in removing earth from any position, but bowlders were most serious obstacles. Those which were met with in the compartments were left till well above the water level, and were then split by plug and feather till they were of sizes to be easily lifted by the dredges in the water shafts; those under the frames had to be removed as soon as found. The earth around them was loosened and removed as far as possible by long steel bars, they were then drilled, and a lewis inserted; a chain to the lewis was fastened to a hydraulic jack, the latter was hooked into a very strong eye-bolt in the roof of the air chamber, and the bowlder pulled out into the compartment. There were three of the hydraulic pulling jacks, two of ten and one of fifteen tons capacity. Some bowlders resisted the whole three united.

Bowlders under the shoe were the most troublesome, as they exposed one face only to attack, and were of necessity under water. Those that projected more than two feet outside of the caisson were not removed. The projecting portions were laboriously chipped off till the caisson would clear them. The mud raised by the dredges was at first dumped round the caisson to prevent the free passage of river water to the air chamber, and after a time this attempt was successful. A clay dam was then built when ever a shoe bowlder was discovered, bags were rammed in wherever leaks showed themselves, and a comparatively dry pit was dug under the bowlder into which the latter was induced to fall. From the pit it was hauled into the air chamber by the jacks, and when there was easily and quickly disposed of.

Shortly after the work began a special "bowlder gang" was organized; these men worked from 11 P. M. to 6 A. M., while all other work in the caisson was stopped, and by this means vexatious delays were prevented. At the end of the first month's work the average settling in a week was six inches. Blasting was now resorted to in order to hasten the work of removing the bowlders. At first great caution was observed, for fear that the concussion might destroy the equilibrium of the water shafts; no ill effects attending the use of small charges, they were increased to the size usually employed in blasting, and were extensively employed. Bowlders fourteen feet long and five feet in diameter were met in the course of the work.

While the caisson was sinking the pressure from the land was greater than that from

the river, and the whole caisson advanced two feet toward the channel. This action had been foreseen, and the masonry base had been made sufficiently large to build the tower in its intended position.

Water shafts. Theoretically the transfer of material from the air chamber to the open air through the water shafts should have been rapid, easy and safe; in practice both danger and difficulty were encountered. The most efficient forms of dredge buckets were tried, but at the very outset the discovery was made that they would not dig the pit under the water shaft, through the material in which this caisson was sinking. At any other point in the air chamber the material could be prepared for the dredges, and properly broken up, but beneath the water shaft was a space, out of sight, and under water, which could not be reached in any effective manner without removing the water.

To excavate this portion a heavy wrought iron cap was placed on the top of the shaft, and bolted on air-tight. The cap was then loaded with stone and compressed air slowly admitted at the top of the shaft. The water was thus slowly forced down, the load on the cap being gradually increased as the water ran out below. When pressure in the shaft was the same as in the air chamber, the pool at the base was bailed out, and a large pit with sloping sides was dug to a depth of 6 or 8 feet below the foot of the iron shaft. During the operation of digging this pit, water was excluded by a circular dam built on the bottom of the air chamber; the dirt was removed at the other water shaft while this excavation was performed. When the pit was finished, water was admitted from the trenches, and when it was full the compressed air in the shaft was allowed to slowly escape at the top; as it escaped the water was drawn from the pit into the water shaft, and great care had to be taken to have a plenteous supply. When the shaft was full, that is when all the compressed air above the water had escaped, the stones and cap were removed, and the shaft was in condition for work. Each shaft had to be cleared out in this manner at intervals varying from one to four weeks; about two days were required for the operation. From this cause, and the wear and breaking of the buckets one shaft was idle most of the time.

When the buckets descended they compacted the material at the bottom, and if left without constant stirring it soon became as hard as the original soil, and the buckets would not touch it. Stone and clay thrown in together always hardened in this manner, the stones were therefore retained till the water shaft had been cleaned out; they were then all removed as soon as work at the shaft began, before any dirt was thrown in; large stones had to be raised one at a time, and sometimes would get into such positions that the dredge could not seize them. In such cases, the men would dive under the shaft, and remove the difficulty—a man with his lungs full of compressed air can remain under water

3 minutes according to Col. Roebling.

The water in the shaft held a very large amount of clay in suspension, this increased its weight so much that a column of the mixture 30 feet high would counterbalance a column of clean salt water 45 feet high, it therefore weighed ninety pounds per cubic foot. As soon as the water in the shaft was allowed to stand quiet the clay settled and cemented all stones at the bottom into a solid mass, the water rose at the same time due to its decreased weight, and more was required to preserve the dynamic balance. This required constant care and watching to see that the pool at the foot was always kept full. After the caisson had sunk so far that the river water could not be relied upon for a supply, a dam was built round this pool that it might hold more water. One Sunday morning the dam round the south water shaft washed away, the water level fell below the bottom of the shaft, and at once the whole liquid column was blown out.

Col. Roebling describes this phenomenon in the following words:

"To say that this occurrence was an accident would certainly be wrong, because not one accident in a hundred deserves the name. In this case it was simply the legitimate result of carelessness, brought about by an over-confidence in supposing that matters would take care of themselves. The immediate cause of the blowing out lay in the washing away of the dam around the pool under the shaft. These dams washed away frequently at subsequent periods, but we had had our experience and our lesson, and were prepared for it. There was unfortunately no man in the caisson at the time, so that experience is lost. Eye witnesses outside state that a dense column of water, fog, mud and stones were thrown up 500 feet into the air, accompanied by a terrific roar, and a shower of falling fragments covering the houses for squares around. This column was seen a mile off. The noise was so frightful that the whole neighborhood was stampeded and made a rush up Fulton Street. Even the toll collectors at the ferry abandoned their tills. There were three men on the caisson at the time including the watchman. He reports that the current of air rushing toward the blowing water shaft was so strong as to knock him down; while down he was hit on the back with a stone, and further than that he does not remember. One of the other men jumped into the river, and the third buried himself in a coal pile. It was all over in a minute. Both doors of the air lock fell open. And the dry bottom was visible through the air and water shafts. Not a particle of water had entered under the shoe into the air chamber, and for the first and only time the caisson could dispense with artificial illumination. As soon as possible a stream of water was passed into the shafts from above, the locks were closed, and in the course of an hour the pressure was restored to fifteen pounds, corresponding to a head of thirty-one feet."

"The first entry into the caisson was made with considerable misgiving, but none of our fears were realized."

"The total settling that took place amounted to ten inches in all. Every block under the frames and posts was absolutely crushed, the ground being too compact to yield; none of the frames however were injured or out of line. The brunt of the blow was, of course, taken by the shoe and sides of the caisson. One sharp bowlder in No. 2 chamber had cut the armor plate, crushed through the shoe casting, and buried itself a foot deep into the heavy oaken sill, at the same time forcing in the sides some six inches. In a number of places the sides were forced in to that amount, but in no instance were they forced outward. The marvel is that the air-tightness was not impaired in the least."

"The nine courses of timber forming the sides of the air chamber were permanently compressed to the extent of two inches, as was shown by protruding bolt heads and the shearing of a number of diagonal bolts. The lower sills of the frames were also torn where they came upon bowlders.

"The weight of the caisson was 17675 tons. The air blew out so suddenly that this weight must have acted with considerable impact in falling through the space of 10 inches. The bearing surface at the time was as follows: the four edges of the caisson 550 feet long and 7 inches wide, amounting to 322 square feet. The five frames each 100 feet long, and 1 foot wide, resting on twelve blocks 1 foot wide, amounting to 60 square feet, and giving a total of 382 square feet to meet the above pressure. This is a rate of 46 tons per square foot."

"But more than one half of the shoe was undermined to a depth of one foot or more which reduced the practical bearing surface by nearly one-half. At the commencement there was therefore a pressure of 80 tons per square foot, no allowance being allowed for impact, which may have doubled this rate. The caisson had settled 10 inches. The shoe had buried itself so as to present a width of twelve inches, and through the crushing of the blocks the frames were in many places resting bodily on the ground. The settling had therefore stopped when a bearing surface of 775 square feet had been reached giving a pressure of 23 tons per square foot."

"The ultimate pressure on the base of the caisson due to the weight of the tower and superstructure will be only 5 tons per square foot; hence the margin of safety against crushing is ample. All the above extreme rates of transverse crushing are within the limits of good yellow pine. The fact that the majority of the blocks did crush is attributable mainly to their irregular bearing and to their shortness; a block of four feet in length will bear a much larger pressure on one square foot of its surface than a block of two feet in length; the same is true in regard to relative breadth. Yellow pine is essentially a heart wood,

and before yielding to compression it will split out sideways away from the heart. In the roof of the caisson no effects whatever were produced by the pressure of posts. The timbers are bolted so close laterally that no yielding sideways can take place. Subsequent examinations showed that the roof of the air chamber has assumed a permanent average depression of four and a half inches, being least in the end chamber, and greatest near the water shafts, where there was the least support by frames, and where these openings had cut the timber through from top to bottom. This deflection never increased any. The amount is comparatively small when we consider that the transverse span is 102 feet between bearings, that the whole caisson and timber above it is a composite structure, bolted together, and that the joints in the timber are butt joints. That amount of deflection is scarcely sufficient to bring all the bolts to a full bearing."

Supply shafts. Brick piers, sufficient in number to support the whole superstructure in case the air should blow out again, were built when the caisson reached its final position. This precaution was very wise, for a fortnight after the filling in of the air chamber began, a supply shaft blew out. These shafts were tubes forty-five feet long and twenty-one inches in diameter, with two doors, one at each end, both opening downward. While a load of concrete was thrown in at the top, the lower door was kept closed by the compressed air beneath it, assisted by two iron clamps; the upper door was then closed, compressed air admitted, and the lower door allowed to fall open, discharging the entire contents into the air chamber. On one occasion two charges were accidentally placed in a supply shaft, and the men above gave the signal to those below to open their door before the one above had been closed. The weight of the double charge was so great as to force the lower door open against the compressed air. Col. Roebling was in the caisson at the time, and thus describes the whole occurrence: "As soon as the door opened the air began to rush out of the caisson with a great noise carrying up stone and gravel with it. The men above ran away, leaving those below to their fate. Any one with the least presence of mind could have closed the upper door by simply pulling at the rope."

"I happened to be in the caisson at the time. The noise was so deafening that no voice could be heard. The setting free of water vapor from the rarefying air, produced a dark, impenetrable cloud of mist, and extinguished the lights. No man knew where he was going, all ran against pillars or posts, or fell over each other in the darkness. The water rose to our knees, and we supposed, of course, that the river had broken in. It was afterwards ascertained that this was due to the sudden discharge of the columns of water contained in the water shafts. I was in a remote part of the caisson at the time; half a minute elapsed before I realized what was occurring, and had groped my way to

the supply shaft where the air was blowing out. Here I joined several firemen in scraping away the heaps of gravel and large stones lying under the shaft, which prevented the lower door from being closed. The size of this heap proved the fact of the double charge. From two to three minutes elapsed before we succeeded in closing the lower door. Of course everything was all over then, and the pressure, which had run down from 17 to 4 pounds, was fully restored in the course of 15 minutes. A clear and pure atmosphere accompanied it. The effect upon the human system and the ears, was slight, no more than was experienced in passing out of the air lock.

"Careful examination was made to see what effect the weight of 30 000 tons, had upon the brick pillars and other supports. Although the pressure on the piers was 12 tons per square foot, these showed no signs of yielding. In the neighborhood of the water shafts and supply shafts, where there were no brick piers or other supports, a slight local depression in the roof took place. The occurrence demonstrated the fact that the pillars were strong enough to bear the whole load, and also proved the necessity of their erection. A few small springs of brackish and fresh water started beneath the concrete under the shoe, but were easily repressed. There was no increase of air leakage.

"It was rather remarkable to notice that there was no rush of air in the immediate vicinity of the supply shaft, not even for several feet up the shaft; the action was one of free expansion in all directions.

"The question naturally arises, what would have been the result if water had entered the caisson as rapidly as the air escaped. The experience here shows that the confusion, the darkness, and other obstacles were sufficient to prevent the majority of the men from making their escape by the air locks no matter how ample the facilities. If the water entered as rapidly as the air escaped there would then be the same pressure of air during the whole time of escape. Now it so happens that the supply shafts project two feet below the roof of the air chamber; as soon, therefore, as the water reaches the bottom of the shaft, it will instantly rise in it, forming a column of balance, and checking the further escape of air. The remaining two feet would form a breathing space sufficient for the men to live, and even if the rush of water was to reduce this space to one foot, there would be enough left to save all hands who retained sufficient presence of mind."

Lighting. Several systems of illumination were tried, and gas proved to be the best. Calcium lights were efficient, but costly; candles smoked excessively, but were necessarily used when it was important to have any particular spot illuminated for a short time. Lamps were not tried as they were considered too dangerous on account of their reservoir of oil. They smoke worse than candles.

The gas was maintained at a pressure about one pound greater than the air in which it

was to burn, by the following arrangement. A gas tank filled with water was placed in the air chamber. A tube passed gas-tight through the top, and projected to within a short distance of the bottom. This tube led up to an open reservoir of water a few feet above the surface of the river. Gas was now forced by pumps through a pipe leading into the top of the tank in the air chamber. It forced water out through the tube already described into the open reservoir above, as this was already brimful the excess ran over the sides. This reservoir was maintained full and overflowing by a small stream of water so that the pressure of the gas was always that due to a fixed head of water. In this way the flicker caused by the stroke of the pumps was avoided.

Fire and repairs. In a wooden caisson there is the greatest danger of fire. Candles blown out in compressed air are at once relighted by the abundant oxygen, and the same is true of lighted wood. A fire broke out in the Brooklyn caisson Dec. 2nd, 1870. The escape of air between the timbers kept up such a plenteous supply of oxygen, that the fire advanced in spite of all the efforts to stop it. At one time it was supposed to be extinguished, but a hole bored into the roof of the air chamber with a long auger showed the fourth course of timber to be a mass of glowing coals. There was now no resource but flooding the caisson. All the engines of the fire department, and several fire boats and tugs were soon pouring their streams down the water shafts. All the pipes of the caisson itself were also put in requisition. The air had to be let out just as fast as the water went in, for any mistake by which the pressure of air should fall suddenly would leave the 28000 tons, which the caisson and its load now weighed, unsupported in the centre, and the result in the present weakened state of the timbers could not be doubtful. Such leaks would be caused that re-inflation would probably be impossible. The flooding was successfully accomplished, and after two days and a half air was again forced into the chamber. No trouble from leaks was found; the swelling of the timber had been beneficial in this respect, and the caisson was tighter than ever before.

Examination showed that above the opening where the fire had started, it had destroyed the third fourth and fifth courses, and had consumed two or three cubic feet of the sixth course. It had burned through the sheet of tin which had covered the fourth course. As far up as the sixth course the timbers had been close together, but that course and those above were laid with intervals of three inches between sticks; the concrete which filled these spaces seems to have checked the fire at once. Some sticks were burned away for 30 feet, but the progress had generally been a gradual process of charring, which extended equally fast in all directions. Timbers which were partly consumed were scraped clean, and the vacant space filled in with cement; those which were entirely carbonized were replaced by yellow pine sticks 8 to 10 feet long, which were forced in by

jacks and wedges. All butt ends were cut off square, and joints were broken as much as possible. To reach the spots where the fire had been, five openings were made in the roof of the air chamber. The largest was 6 feet square, the others from 3 to 4 feet square. Eighteen carpenters working night and day for two months were required to complete the repairs.

The work was excessively unhealthy. The men were laboring in compressed air, foul with the gases of wet and burned wood, in all sorts of cramped positions in narrow apertures. Candle smoke and powdered charcoal added their noisome influence to complete the pestilential character of the atmosphere.

March 11th, 1871, the air chamber was completely filled with concrete, and caisson work on the Brooklyn side was done. It rests on hard pan 44.5 feet below mean high tide.

NEW YORK CAISSON.

The New York caisson was in most respects a duplicate of that already described; it had however a thin iron skin to the air chamber as a protection against fire, and air leakage. Boiler plate No. 6, the iron used for this purpose, was selected that it might buckle easily when expanded by heat, and thus avoid excessive strains.

The material to be excavated was much less troublesome than on the Brooklyn side, being largely composed of sand and mud, which the dredges could remove without difficulty. The troublesome clearing out of the water shafts was thus avoided; in addition to this a large proportion of the earth could be raised by the air pressure alone. 50 pipes from $3\frac{1}{2}$ to 4 inches in diameter, leading from the open air to the air chamber where they were closed by through-way cocks, were inserted. Flexible hose was connected to their lower ends, and the nozzle run into the loosened earth. Turning on the cock let the air rush up through the tube with such violence as to carry sand, mud, and gravel with it. The hose was found liable to get clogged up, and was soon replaced by rigid iron tubes which reached to within a foot of the floor; earth was piled up round the end, and the cock turned on with the same result as before. As the caisson sank and the pressure increased, the orifice was decreased until it was only two inches in diameter; with this sized opening and the heavy pressure the same amount of earth was removed with less waste of air.

There was but little difficulty found with the lower parts of these simple sand pumps, but such was not the case at the top. The stream of flying sand had to be deflected that it might flow into the river, and not fall back from a great height upon the caisson and surrounding wharves and boats. How to deflect it proved to be a problem of no little difficulty. Iron elbows (both wrought and cast) were tried, but a thickness of one and a

half inches was cut through in an hour or two, often in a few minutes. The parts of the elbows which were perforated were then made replaceable by thick plates of Franklinite iron. These lasted about two days. At last elbows were given up altogether, and the discharge was allowed to strike against thick blocks of granite. This proved successful, although some boatmen and laborers were wounded by the fragments.

The caisson now rests on bed rock at the depth of 78 feet below the river surface at high tide.

Physical effects of compressed air. While entering a caisson through the air locks a very unpleasant feeling in the ears is experienced; by holding the nose closed and trying to blow through it, this feeling is avoided; another method is to swallow continually. Either operation has for its object the opening of the Eustachian tubes, that the compressed air may enter through them, and relieve the excess of external pressure on the ear drum. Before entering the air lock persons should always try this blowing with the nose closed, if there is no feeling in the ears it shows that the Eustachian tube is closed, and if they endeavor to pass through the lock their ear drums will certainly burst. Several cases of this kind occurred.

In locking out the expansion of the air produced great cold, a fall of the thermometer from 80° to 40° F. was usual till a steam coil was introduced into the air lock.

Persons who are extremely deaf can often hear perfectly in the caisson; unfortunately the deafness returns as soon as the air pressure is again lowered to its normal condition.

Sounds are raised in pitch, a bass voice sounding like a shrill treble. It is impossible to whistle, and more difficult and fatiguing to speak than in air of the normal pressure. Respiration becomes more frequent, and the inspirations are deeper. On first entering the caisson the pulse becomes more rapid, but in from half an hour to two hours according to the person under trial, it returns to its natural condition. Bodily temperature is generally higher, due to slow evaporation from the skin, and for the same reason the quantity of perspiration seems to be enormously increased; careful experiment shows that this is not really so.

Caisson disease. The New York foundation was so deep that an unusual opportunity of studying the peculiar sickness to which laborers in compressed air are liable was given to Dr. Andrew H. Smith, Surgeon to the New York Bridge Co. His essay on this disorder which he aptly terms caisson disease was awarded the prize of the Alumni Association of the New York College of Physicians and Surgeons in 1873. All the facts I shall state about this disease are derived from this essay. In from 10 minutes to 4 hours from the time of leaving the caisson, the patient is seized with sudden and violent pains, usually in the knees, whence they creep up the back to the shoulders and arms. They are

sometimes accompanied by swelling and discoloration, although they generally last but a few hours.

Paralysis sometimes follows shortly after the pains begin, and although all sense of external touch or scratch is lost in the paralyzed parts, the internal pain is entirely unrelieved. The patient, even in such a violent case as this, usually recovers in a few days. Pain in the stomach and prolonged vomiting were experienced in 24 per cent. of the 110 cases which Dr. Smith attended.

The probable cause of this peculiar and very painful disorder is that carbonic acid, oxygen, and nitrogen are dissolved in blood to a very large extent under high pressure, and tend to resume their gaseous state when the pressure is removed. The effect on a patient who passes suddenly from air at a great pressure to the ordinary atmosphere, is thus the same as would be produced by injecting bubbles of these gases into the veins. Too rapid locking out by giving the body no time to free the veins from these bubbles is the direct cause of the disorder in many cases. A return to the compressed air should if this theory be true, relieve the patient at once, and such is the case. Those who had the courage to try this Spartan method received almost instantaneous relief.

The physical condition of the laborers as regards corpulency has a very marked effect as is shown by the following table which Dr. Smith constructed from his records and those of the paymaster of the New York Bridge Co.

RELATIVE HEALTH.

	SPARE.	MEDIUM.	HEAVY.	TOTAL.
Lost little or no time from sickness	25	14	3	42
Taken sick	28	22	36	86
Paralyzed	2	3	8	13
Died			3	3

The system is in a very much weakened state from the effort necessary to absorb these bubbles in the blood; for an hour little or no exercise should be taken, and for this reason it is very important to have air locks at the top of the shaft. Before locking out hardly any effort is needed to mount the steps, while immediately after, the same exertion produces most excessive fatigue.

Care of workmen. The following suggestions of Dr. Smith coming as they do from one who has been practically familiar with this disease seem to be of value.

"The men should be under control to a certain extent during the intervals of work. Excessive use of intoxicating liquors should be prevented; regular hours for sleep and for meals insisted upon, and sufficient nutritious, digestible and properly cooked food

should be provided. The men should sleep in comfortable beds and in properly ventilated apartments."

"All this is manifestly unattainable if the men live in homes of their own choosing. If therefore any great work by the aid of compressed air is to be undertaken, the preparation for it should include whatever is necessary for housing and feeding the men at a convenient place near the work. For this purpose temporary barracks may be erected in an enclosure, which the men are not permitted to leave except under proper restrictions.

"The food should be furnished by the employers, be of good quality, embrace a sufficient variety, and be prepared by competent cooks. Sleeping apartments should be provided allowing at least 800 cubic feet of air space to each man, and with efficient ventilation.

"A hospital should be arranged with a sufficient number of beds, and fitted with every appliance for treating patients *during their entire illness*. The hospital to be in charge of a competent steward, under the supervision of a physician, who should attend a portion of each day.

"Of course this implies that only single men shall be employed, and that they shall at the outset agree to a *quasi* military rule."

"When the number of men is considerable, as will be the case in any large work, the company could carry out the above suggestions economically to themselves, and after deducting the cost from the pay of the workmen, there would remain to the latter more than they would have left after paying their board in the usual way. At the same time the men would be so much more comfortable, than if left to provide for themselves, that they would value the position, and the fear of being discharged would be a sufficient restraint upon them. The tendency, too, would be towards securing at the beginning of the work, a set of men who would continue to the end. These men commencing when the pressure was slight, would not be affected by its gradual increase, thus avoiding the great danger which attends those who begin work for the first time after the pressure has attained a high figure. I am satisfied that it is by attention to this point more than by anything else, that the suffering and danger resulting from the use of compressed air may be diminished."

"New hands should not be allowed to work in the caisson more than one watch in each day for the first week."

(At first the time is divided into two watches of four hours each, separated by an interval of two hours. As the depth increases the watches decrease, till at 78 feet the two together should not be more than four hours, and the interval of rest should be increased to four hours.)

"After this half of the usual second watch might be added for another week, at the close of which the full time could be entered upon."

"Since much of the work on the pier above, as well as in the caisson below, is unskilled labor, it could readily be so arranged that the gangs could work on alternate days, in the compressed and in the external air. The advantage of an interval in the caisson work is immediately apparent, the cases of sickness being notably diminished by even a single day's intermission."

"The following rules are important and their observance should be insisted upon:

1. Never enter the caisson with an empty stomach.
2. Use as far as possible meat diet, and take warm coffee freely.
3. Always put on extra clothing on coming out.
4. Exercise as little as possible in the first hour after coming out, lie down if possible.
5. Use intoxicating liquors sparingly, better not at all.
6. Take at least 8 hours sleep every night.
7. Never enter the caisson if at all sick.
8. See that the bowels are open every day.
9. Report at once all cases of sickness, even if they occur after going home."

"The men should be selected as far as possible from those who are of a spare and wiry build, and no one should be accepted who has a tendency to corpulency."

"The lock tenders should be selected with special reference to their trustworthiness, and, if it is found that they can not be depended upon, the air locks should be so arranged that the aperture can be graduated from time to time by the engineer in charge, so as to prevent the possibility of a too rapid charge of pressure."

"In entering the caisson, at least three minutes should be allowed in a lock for each additional atmosphere of pressure, and at least five minutes in coming out."

"As for the number of hours of work daily, the rule given by Mr. Collingwood will serve as a general guide: 'Taking it for granted that 12 hours is the extreme time that a man can labor without detriment to health, in an ordinary atmosphere, then with a pressure of two atmospheres, or 15 pounds additional pressure, he can labor about one-half that time; with three atmospheres, about one-third of that time; and with four atmospheres about one-fourth of that time.' In other words, the time is inversely as the pressure."

"Whenever, for any cause, a sudden increase of pressure is demanded the watch should be shortened to a corresponding extent."

"The air in the caisson should be maintained in a sufficient degree of purity, as there may be a wide difference between the amount of air required to supply the necessary

mechanical conditions for carrying on the work, and the quantity demanded for the health of the workmen. A closed bottle of lime water with a tube reaching to the bottom, and a second tube from the cork to a syringe gives the means of drawing a known quantity of air through the water; the precipitate of $CaCO_3$ obtained in the air chamber of the caisson should not be greater than that obtained in a fairly ventilated room from the same number of strokes of the syringe."

MASONRY SUPERSTRUCTURE.

Approaches. The approaches of the East River Bridge are models of substantial and elegant masonry, The facing of the piers and the spandrel walls are of cut granite, the body of the piers, and the intrados of each arch is of brick. The New York approach is so high that it affords ample space under its lofty arches for large ware-houses. It has been carefully planned and built with this idea in view. Fine specimens of oblique arch work are to be seen where this approach crosses the smaller streets. The Brooklyn approach is not so high and is only half as long; there will be a little space devoted to ware-houses in the higher part of the approach near the anchorage. The streets are crossed by plate girders instead of arches.

Towers. Both towers and anchorages, except those parts which had to be left till the cables were laid, were completed by the end of the year 1876. The thrust from the pointed arches in the towers fell originally at a point 2.5 feet outside the centre line of the side shafts, at the level of the bridge floor, but when the outer cables had been drawn in toward each other, to stiffen the bridge against lateral vibration, the thrust fell 6 inches inside of this centre. This is a position of great stability. The saddles (figs. 10 and 13) are massive castings weighing 27 tons each. They rest on steel rollers $3\frac{1}{2}$ inches in diameter.

Anchorages. The anchorages are entirely artificial, and are so constructed that the weight of masonry on the anchor plates is $2\frac{1}{2}$ times the vertical strain on the anchor chains where they join the plates. A vertical section of one of the anchorages is shown in fig. 12. The anchor plates (fig. 16) are huge star like castings so arranged that the bars of the anchor chains rise in two sets one in front of the other. These are separated by proper knuckle plates at the joints. They rise vertically (fig. 12) for 26 feet, then bend in the arc of a circle about 49 feet in radius, till they are tangent to the curve of the cables. At this point the two sets of bars branch out into 4 tiers of eye-bars as shown in fig. 3. There are 8 of these eye-bars in the upper tier, and 10 in each of the others. Steel pins 7 inches in diameter connect these eye-bars two and two. Each pin passes also through the central hole in a shoe (fig. 6) placed between the two eye-bars, which thus

transmit any strain brought on the shoe, directly to the anchor chains and plates.

There is a groove round the outside of the shoe and in this lie the wires comprising a single strand of the cable. Fig. 3 shows the first strand laid up, and its shoe in position. There are 19 shoes and 19 strands in the cable.

Unlike European suspension bridges where the anchor chains are usually left open to inspection, these are well painted and then built in solid in the masonry; reliance being placed upon the property which hydraulic cement possesses of protecting iron from rusting.

BRIDGE PROPER.

Cable material. The selection of the material of which to make the cables was a question of no little complexity. Iron wire is much more uniform than steel, but it has a much lower elastic limit and modulus of rupture. This would necessitate the manufacture of much larger cables than if steel were used; their weight would be greatly increased, and also the surface presented to the wind; therefore, if steel wire could be drawn sufficiently uniform to answer the requirements it was on all accounts to be preferred. Experiments with sample wires furnished by different wire drawing firms seemed to indicate the affirmative, and steel was decided on. The wire was then contracted for, a bond of $50 000 being required to ensure the performance of the contract. When received it was required to pass successfully the following tests before being accepted.

"First. One ring in every 40 will be tested as follows: A piece of wire, 60 feet long, will be cut off from either end of the ring, and it will then be placed in a vertical testing machine. An initial strain of 400 pounds is now applied which should take out every crook and bend. A vernier gauge, capable of being read to $\frac{1}{1000}$ of a foot, is so attached as to indicate the stretch of 50 feet of the wire. Successive increments of 400 pounds strain are then applied, and the vernier read each time, till a strain of 1600 pounds is reached.

"The conditions are now as follows: That the amount of stretch for each of these increments shall be the same, and that the total stretch between the initial and terminal strains shall not be less than $\frac{97}{1000}$ of one foot, equal to $\frac{1940}{100000}$ of the 50 feet. And furthermore, on reducing the strain to 1200 pounds there shall be a permanent elongation not exceeding $\frac{1}{100000}$ of its length.

"The same wire will then be subjected to a breaking strain, and the total amount of stretch noted. The minimum strength required is 3400 pounds, equal to an ultimate strength of 160000 pounds per square inch. The minimum stretch when broken shall have been 2 per cent. in 50 feet, and the diameter of the wire, at the point of fracture shall not exceed $\frac{15}{100}$ of one inch.

"Second. One ring out of every five shall be tested by having a piece 6 feet long cut off, and placed in a testing machine with vernier gauge, so attached and graduated as to read the stretch of 5 feet in length to $\frac{1}{10\frac{1}{000}}$ of one foot. When the strains shall be applied in the foregoing order, and the vernier read at each point respectively, if the results correspond with the requirements for the 50 feet lengths, as regards modulus and limit of elasticity and ultimate strength, and the stretch of 5 feet of length exceed $3\frac{1}{2}$ per cent of its length, the ring will be accepted; otherwise it will be rejected.

"Third. Every ring will be tested by having a piece 16 inches long cut from either end, and placed in a testing machine, having a vernier gauge so arranged as to include one foot in length of the wire, and shall be graduated as finely as practicable. Each piece shall be subjected to the same strains, mentioned for the 5 feet lengths, and the results must correspond with the requirements above mentioned, excepting that of the ultimate stretch.

"These shorter pieces are used to expedite the testing and to economize wire; but the requirements in connection with the 50 feet tests will be insisted on, and any doubts as to results with the shorter pieces may be solved by testing a piece 50 feet long. And in case 1 ring in 40 should not be a sufficient test of the quality, then the inspector can select, at closer intervals, rings for 50 feet tests. If want of uniformity is suspected, a piece of 5 feet in length may be taken from the other end of the ring.

"Fourth. Every ring will be subjected to a bending test by cutting off from each ring a piece of wire one foot long, and coiling it closely and continuously around a rod $\frac{1}{2}$-inch in diameter, when, if it breaks, it will be rejected."

After passing these tests the wire was dipped once in raw, and twice in boiled linseed oil, the rings were spliced end to end, and the whole wound on large drums. The splice employed (fig. 19) was very simple, and was found to have 95 per cent. of the strength of the original wire. A right handed screw thread was cut on one of the ends, and a left handed thread on the other, and a short piece of tube with corresponding female threads was screwed on both at the same time. The effect of turning the tube was evidently to bring the ends of the wires together. At first the ends were cut off square before the thread was cut on the wire, but it was found that in running off the drum in later handling, one wire was apt to unscrew. This was avoided by cutting the ends on a bevel, as shown in fig. 19. Any tendency which one wire had to turn in the tube, clamped it only the more firmly. When the jointer had been screwed up till the beveled ends of the wires were in firm contact, the whole was cleaned and galvanized, and was thus made as safe against rust as any part of the wire.

Auxiliary structures. The strength of a cable is evidently the greatest when all

the wires of which it is composed bear equal portions of the load. To ensure this each wire as soon as it was laid was strained till its deflection from the right line joining the two highest points of the catenary was exactly the same as that of a standard wire known as the guide wire. This process was called "regulating," and required men to be stationed at three points of the river span, and at the middle points of the land spans. It was their duty to signal to the parties who were straining the wire the instant that the deflection was exactly right. These men were supported on platforms called "cradles" suspended in mid air on four cradle cables. Three of these were $2\frac{3}{8}$-inch, the other $2\frac{5}{8}$-inch crucible cast steel wire rope. Fig. 11 gives an elevation and ground plan of one of the single cradles, from which the wires in two cables were regulated. The cradles were of oak, the bottom being an open iron grating to allow free passage of the wind. The strain on the cables when in use was about $30\frac{1}{2}$ tons, their breaking strain 90 tons. To reach the cradles a foot bridge was necessary. One side was supported on the large cradle cable, the other on a cable of its own. The floor consisted of oak strips two inches apart. It is shown at *a*, fig. 11. It was successfully protected against excessive undulations by inverted catenary storm cables, to which it was securely stayed. The maximum strain on a foot-bridge cable was 86 tons, the margin of safety being 3.7. To draw the wires across the river two "travellers" were provided. These were endless bands of $\frac{3}{4}$-inch galvanized steel rope, which passed round a combination of wheels on the Brooklyn anchorage, shown in fig. 7, thence over the towers to the New York anchorage, round a couple of large sheaves there and back over the towers to the Brooklyn anchorage again. The large wheel on the Brooklyn side, 11 feet in diameter with a double groove on its circumference for the traveller which embraced it for nearly 360°, was revolved by a powerful steam engine. The "traveller" was in reality nothing more than an excessively long belt, such as is used in every machine shop. To relieve it from excessive tension it was supported in friction sheaves at each cradle (fig. 11) and also where it passed over the towers. Each traveller was so hung that while one-half of it was over the position which an outside main cable was to occupy, the other half was directly above the inner main cable on the same side of the bridge.

Two $\frac{5}{8}$-inch wire ropes were provided as hand rails for the foot bridge, as well as four "pendulum cables" used to support iron rods with leaden weights on their lower ends to keep the two parts of each strand of the main cable apart while they were being laid, and thus prevent their being tangled by the wind. These were found to be unnecessary and so were not used.

A cable $1\frac{3}{4}$ inches in diameter called the carrier was used to support the weight of the heavier ropes as they were hauled across the river. One other rope which was eventually

used to help support the foot bridge, completes the list of auxiliary cables which had to be put in position before cable making could even begin. The operation of getting these 17 ropes across such a crowded thoroughfare as the East River, and over the roofs of the lofty buildings in New York and Brooklyn was performed under the direction of Mr. E. F. Farrington, who had had previous experience in this difficult and dangerous work at Niagara and Cincinnati. His description can certainly not be improved by one who was not an eye witness. I therefore quote it *verbatim*.

"The two travellers were the first to be taken over. The reel containing the first rope was placed on a wooden axle, in a frame on one of our stone scows, at the foot of Brooklyn tower. The end of the rope was then hoisted over the tower, and drawn down into the yard, when a manilla rope leading to a steam engine at the anchorage was attached to it, and it was carefully hauled to the anchorage and made temporarily fast there. Fenders and trestles were erected, and men were stationed on the roofs of the intervening buildings to protect them; the operation was entirely successful.

"The scow containing the reel with the remainder of the rope, was then towed over the river to the dock at the foot of the New York tower, and the bight of the rope as it unreeled was allowed to sink to the bottom. The scow was made fast to the dock, and all the rope on the reel was coiled at the foot of the tower after which the end was hoisted to the top of the tower, and drawn down and fastened to one of the grooved drums of the stone hoisting engine.

"It was at first supposed that the ropes would have to be hoisted out of the water on a Sunday morning, when there were few vessels in the way; but by frequent observations I learned that we could get from 4 to 8 minutes clear water on any day of the week, and it was resolved to make the attempt as soon as we were ready.

"Engineers Martin and McNulty took possession of the roadway on the tower, to watch for an opening. Foreman Dempsey with some workmen was left on top of the tower; while I clambered up on the hoisting frame, to note the deflection, with William Brown, carpenter, to pass signals to the engineer of the hoisting engine, when to start and when to stop.

"A tedious wait of more than half an hour followed. At last I heard from Mr. Martin, the welcome words, 'Go ahead!' and passed them to Brown, who signalled the engineer. In a few seconds the rope began to move; there was a ripple around it in the water; it began to draw away from the dock toward Brooklyn, and soon we could see the other part coming from Brooklyn towards us. Faster and faster the space of clear water between the two parts narrowed, and in four minutes from the time of starting, it swung clear of the surface of the water with a sparkling 'swish' amid the cheers of spectators on the

wharves and ferry-boats, and the shouts of our own workmen.

"Up went the rope, and when it reached the level of the roadway, the engineer was signalled to go slow, and the speed lessened. When it was within a few feet of its proper deflection, 80 feet, I passed the word to stop the engine, which was done, but not till the rope had reached a point somewhat above the intended deflection, though in time, however, to prevent any damage to the rope. This occured August 14. The second rope was taken over in the same manner, on the same day.

"These ropes were securely fastened on the top of the tower, and the two ends were then hauled over the streets and roofs, to N. Y. anchorage, much in the same manner as in Brooklyn. The ends were next spliced together around the driving and guiding wheels, thus forming one endless rope, capable of being worked to and fro to draw loads, and to carry burdens. It is arranged to run in wood lined wheels on the towers, and although it has seen much hard service, it bears no perceptible marks of wear.

"The two parts of the other traveller, were taken over by being lashed to the first one, and then carried over by steam. After being taken over, the ends were received on the two anchorages, the lashings were cut loose by men sitting in 'boatswains' chairs'—a rude contrivance much used by riggers -which were arranged to slide on the first traveller. This somewat novel feat was accomplished by Trims, Supple, Colme and Carrol, on the first rope. The second was cut by Miller, Arnold, O'Neil and myself.

"The carrier was got over in the same manner as the first travellers—through the water. The tug in towing the scow across, made a detour down stream, so that when an attempt was made to draw the rope out of the water, the side strain was so great as to pull it out of the three-foot wooden wheel, in which it was running on the tower.

"James O'Neil was injured at that time by being struck by a piece of plank, which was thrown against him by the falling rope. This accident, I am happy to state, is the only one which has happened on this part of the work. The rope was replaced on the wheel, and a guiding sheave was put on outside the tower, and it was then hauled up without further difficulty.

"After being hauled out of the water, the end was taken from the grooved drum, and hoisted to the tower again, on the land side and fastened to a snatch-block which ran on the traveller, a manilla rope some 300 feet long was made fast to the end of the carrier, and the block was allowed to slide down on the traveller, toward the anchorage, carrying the end of the wire rope with it. It ran down 350 feet by its own gravity, the bight remaining coiled on the dock. When it would go no farther in this way, men pulled it along to the anchorage by the manilla rope; there a tackle was attached, and it was strained up to its correct deflection by steam, and fastened by a socket and stirrup.

I found it lessened the danger and the labor to hang the end of the rope to the traveller, as above described.

"To get over the five other large ropes, I adopted the plan which I used so successfully at Niagara Falls, namely: by suspending the weight of the rope to be hauled on the carrier, and hauling by a traveller or a manilla rope worked by a steam engine. The first cradle cable was hauled by the traveller; but this plan did not work well, owing to the frequent slipping and breaking of the belt, which transmitted the power to the traveller. This rope was delivered in New York, and it cost much labor to get it into position for running over, besides our trouble with the traveller.

"It was therefore determined to land the remaining ropes at the foot of Brooklyn tower which would bring them at once into position: and to do the hauling by a manilla rope, worked on the grooved drum before mentioned. The operation was conducted as follows:

"The manilla rope was first drawn over the river by the traveller, and made fast temporarily on Brooklyn tower. It was suspended from the carrier by small clevises (fig. 8) which prevented the bight from dropping in the way of passing vessels, and at the same time allowed it to move freely. These clevises were put on 80 feet apart. Another rope was drawn up from Brooklyn anchorage in the same manner, and one from New York anchorage to New York tower.

"A stick of oak timber, 6 by 10 inches and 10 feet long, was fastened by stirrups on the top of the carrier just outside of Brooklyn tower on the water side. To this a large grooved cast iron pulley was hung. A 14-inch leading block, was also made fast to this stick near the iron sheave, and through it a 4-½ inch manilla rope lead to an engine on the dock. By this rope the end of the wire rope was hoisted from the reel on the dock below, and run over the iron pulley. The hauling rope from New York was then made fast to the end of the wire rope, and the New York engine was started, and with the aid of the dock engine in Brooklyn, the wire rope was hauled 10 feet toward New York, and then the first hanger (fig. 8) was put on.

"These hangers were grooved iron sheaves, 8 inches in diameter, to which a pair of 'sister hooks' were attached, in such a way as to allow of their being opened, and slipped over the carrier in the most expeditious manner. The cables were lashed below the hooks by ½-inch hemp ropes. Thus the hauling line pulled the cable along, while the hanger ran easily on the carrier, and held the weight of the cable lashed below. The hangers were put on about 60 feet apart. The oak stick was used to prevent the carrier from being strained at too sharp an angle by the weight of the cable and hoisting line. A buggy (fig. 9) hanging on the traveller was used for two men to stand in to put on the hangers.

"In this way a cable was drawn to the New York anchorage; a line from that anchorage being attached as soon as the end of the cable reached the tower. 'Twas necessary to use the line at Brooklyn tower to assist in lifting the weight of the cable, until 350 feet had been run out, after which the New York line did all the work. I also had to 'fleet' the New York line 400 feet, on the main span, to help the line from New York anchorage.

"When the end of a cable reached New York anchorage, a wrought iron socket was put on, and it was attached to an anchor iron, in the masonry by a stirrup. Meanwhile the end remaining on the reel was taken off and coiled on the dock, and then hoisted to the top of Brooklyn tower, and hauled to the anchorage by the line before mentioned, the weight being held by hangers on the carrier.

"The cable was next strained up until the hangers were relieved from its weight, when they were taken off by men, who went down in buggies for that purpose. The buggies ran on the carrier, and were hauled back by the traveller. The cable was strained up still further, to the required deflection, in the centre of the main span; then it was cut off, and an attachment was made by a socket and stirrup, as in New York. On the towers the cables ran on two grooved oak wheels, three feet in diameter, and six inches thick. When a cable had been taken over and fastened, it was lifted out of these wheels by powerful screws set in a strong frame, and lowered on to permanent oak blocking. This plan was pursued with the two foot bridge cables, and two cradle cables.

"Nearly four days were consumed in getting over the first, by the traveller, and fastening it, while the last one was drawn over in less than nine hours, and fastened in less than five hours more; thus showing the superiority of the last plan over the first, and the increased efficiency of the workmen through practice."

Cable making. The method of holding the shoes round which the wires forming the strands of the cables pass has been already explained under the head of the anchorage. It would evidently be impracticable to pass the wire round a shoe in its final position there described, and hence a temporary support to hold it while the strand was making was provided. Furthermore there are great advantages to be attained in making the strands higher than their final position: by so doing the wires in each can be regulated without inconvenience from the parts of the main cables already constructed and in their final position; the wires are also under a greater strain by this method, and this at once removes any bends or waves that they may contain, and tests them nearly up to the strain they will eventually have to bear in the completed bridge. For all these reasons the temporary supports should be farther from the river than the end of the anchor chains.

Fig. 17 gives a perspective veiw of the support actually used. It was called a "leg," and was made of cast iron. These legs were made of such a length that the strand,

which was raised slightly by passing over temporary supports at the towers, hung 60 feet above its final resting place at the middle of the river span. A guide wire, held also by the leg, was first strained till it was at the exact deflection required for the strand, and the wires to form the latter were then brought to the same tension, as will be described hereafter.

The wire, oiled and wound very tightly on strong drums with powerful brakes, stood on the *Brooklyn* anchorage near the leg. The outer end was passed forward (fig. 17) toward the river round a travelling sheave fastened permanently to the traveller, back to the shoe supported on the leg, round the rear of the latter in the groove, and forward to a pin on the side of the leg, where it was temporarily made fast as indicated in the plate. The travelling sheave was a large, light, open-work wheel five feet in diameter, and was suspended from the traveller by a goose-neck, which allowed the latter to pass freely over the grooved friction wheels which supported it at the cradles and towers.

On each traveller there were two of these sheaves, so placed that when one of them was at the New York anchorage over an outer main cable, the other was at Brooklyn in the same position with reference to an inner main cable. When the traveller starts the sheave moves with it in the direction of the arrow head, that is from Brooklyn to New York. This causes the wire to unreel from the drum. That half marked standing wire, remains apparently stationary, the other half travels from the drum towards the river at double the rate at which the traveller is moving; the tension is so regulated by the brakes on the drums that the wire shall not sag too much. When the sheave has passed the first tower, the standing wire is placed in its temporary supporting rollers on the saddles (figs. 10 and 13), and that part of it between the anchorage and tower is "regulated" by men on the tower, that is it is made to hang level with the guide wire by pulling with a pair of powerful machine fingers, which grasp the wire without denting or weakening it. When this portion is satisfactorily regulated the wire is temporarily seized with spun yarn on the first tower; when the sheave has passed the second tower the middle span of the standing wire is regulated in a similar manner from that tower, so that by the time the sheave reaches the New York anchorage and the bight of the wire is placed over the shoe there, the New York land span is the only part of the standing wire which has to be regulated. When this span has been regulated and seized by the party at the New York anchorage, what was the running wire, is placed on the temporary supporting rollers on the towers, and the portion between the New York anchorage and tower is regulated from the New York tower. The river span of this wire is next adjusted by men at the Brooklyn tower, and finally the Brooklyn land span by those on the Brooklyn anchorage.

All the standing wires are thus regulated from Brooklyn towards New York, and the running wires in the opposite direction; the result is that all slack is passed forward to the drums. While the running wire is being regulated the direction of motion of the traveller is reversed, and the sheave returns to Brooklyn idle; but its fellow on the other half of the traveller is now moving from Brooklyn with a bight of wire which it is laying up in the inner cable. By constructing two cables at the same time the traveller is never idle. The running wire is usually completely regulated by the time the idle sheave has returned to Brooklyn, and as soon as a bight has been passed over it, the motion of the traveller is again reversed, and two more wires thus laid up. By this arrangement four wires across the river are laid for every complete journey of one sheave across the river and back, two in an outside cable, and two in the nearest inside cable.

The running and standing wires were carefully kept separate, and all delay and confusion thus avoided. When the last wire of a strand had been laid the wire was cut off of such a length, that when it was spliced to the first end, which up to this time was fastened to the side of the leg, the last span would hang at the right height. This was a very delicate operation, and several trial cuts were generally made, before the true length was obtained. The two ends were now spliced in the usual manner, and the strand, a great skein of wire was complete.

Men now rode down the new strand in buggies, and at intervals of about 20 inches, bound it with four turns of No. 14 annealed galvanized iron wire, into a compact little cable about $3\frac{1}{2}$ inches in diameter. Before being bound, the wires were compressed by a kind of tongs. The operation is shown in fig. 9.

Regulating the strands. The strand being now complete the shoe was grasped by two heavy iron bars bolted to a double steel plate (fig. 18). The bars were attached to a very strong system of blocks and falls, and the shoe was drawn back $\frac{1}{8}$ of an inch, and raised from its seat on the leg, the leg was removed and the shoe let forward till it rested between the eyes of the two anchor bars destined to hold it permanently. A short pin was then driven through the eyes and the central hole in the shoe, to hold the strand till it was regulated. At the same time the strand was raised from the rollers in the saddles, on which it had temporarily rested, and lowered into its final position by a powerful screw lifting jack.

If all the guide wires had been exactly the right length the strands should now have hung exactly alike, but changes in temperature on different days made it impossible to attain this desirable result. A change of 3° F. raises or lowers the middle point of the river span one inch. The strands themselves then required regulating. The highest was the one adopted as the standard, and the others were brought to this deflection by drawing their shoes back

by the tackle before used in letting them forward, till they hung satisfactorily. An iron segment of the proper thickness (fig. 6a) was now inserted between the shoe and the pin which holds it, and the tackle removed.

Wrapping the cable. This, the final operation of cable making was performed by a machine (figs. 14 and 15) manipulated by men in a carriage running on the nearly finished cable. The wrapping machine consists of a light drum revolving on a cast iron barrel. The barrel was hollow, and was arranged to slide longitudinally on the cable before it was wrapped, without turning about its axis. On this same barrel there was a ring with a steel facing, and two arms at the opposite extremities of a diameter. One arm carried a small grooved roller, the other a weight. The whole machine was made in two parts, so that it could be put over the cable, and clamped together with bolts.

The operation of wrapping was performed as follows:

The outer strand lashings for a distance of a few feet from the saddle were cut, and as many of those on the inner strands as could be reached, removed. Close to the saddle the cable was grasped by a "squeezer," which consisted of two halves of a ring whose inner diameter was that desired for the cable to be wrapped; these halves could be powerfully drawn together by strong bolts. They were made of steel, 1⅞ inches thick and 3½ inches wide, and are seen in fig. 14, to the right of the wrapping machine proper. The two halves of the wrapping machine were now put on the cable, with the steel-faced ring next to the saddle; they were bolted together, and the whole was slid along the cable till it was as near as possible to the saddle. A squeezer was then put on 10 inches in front the wrapper, which was thus between two squeezers. A carriage was also put on the cable to support the men who turned the wrapper. The drum was filled with wire, one end of the latter was fastened near the saddle, the bight put over the small roller, and the ring turned by its handles in the direction shown by the arrows, and the drum in the opposite direction. This action wound the wire on the cable under great tension. In the steel face of the ring there was a small groove, which was tangent to the circumference of the inner surface of the barrel, and also to the small roller; the wire payed out through this groove. When the ring had made one complete revolution, the wire was under such tension that it could not rise and lie upon the wrapping already laid, but instead forced the ring and barrel ahead. The wire itself thus moved the machine along, and was sure to be laid close and even, as the barrel did not slide easily on the unwrapped cable. As soon as the wrapper came up to the squeezer in front of it, the one in rear was removed and put on 10 inches farther to the front, and the one in the way removed. As the cable was wrapped in rear there was no longer any need of a squeezer to hold it in place, so the one removed was at once put on again 10 inches in advance of its fellow. Meanwhile the

strand lashings had been cut for a few feet ahead. There were four of these machines at work at the same time. Two were wrapping toward each other in the main span, and one was wrapping each land span from the tower toward the anchorage. The two in the middle span were turned in opposite directions, so that when they met, their wires were spliced together, and the joint galvanized. The cable was pounded with wooden mallets when the squeezers were applied, and then the whole saturated with oil till every space was filled. As soon as a few feet were wrapped, the whole was painted, and other coats were applied till the spaces between the wires were hardly visible.

Suspenders. These are of $1\frac{3}{4}$ and $1\frac{5}{8}$-inch steel rope, and are fastened to the cables by suspending rings, clamped in place in a manner entirely similar to that employed in putting on the "squeezers." The rings are so forged that their plane is vertical when they are clamped on the cables; all tendency to cut in is thus avoided. On the under side each is shackled into a wrought iron socket on the upper end of a suspender. These sockets are of the form indicated in fig. 4, where two vertical sections at right angles to each other are shown. The end of the suspender rope was passed through the hole from below, and the wires were untwisted and opened so as to fill the conical space. Coarse wire pins were then driven in from above till no more could be forced in—a smaller size was then used, and this was continued till very fine wire refused to enter—all vacant spaces were finally filled with melted lead. The rope parts before it can be drawn out of these sockets. The lower end of the suspender rope is fastened in the same way in a cast iron socket (fig. 5 shows the elevation and ground plan), which is attached by two long screw bolts to one of the transverse roadway bearers. The bolts are made with a very long screw thread so as to allow a great adjustment in the height of each bearer. When finally adjusted the nuts are prevented from moving by jam nuts and other contrivances.

At the anchorages the floor beams are above the level of the cables for 250 feet. For this distance the roadway bearers, are supported on posts bolted to the top of castings made to fit the cables, and clamped to them like the suspending rings.

Roadway bearers. After the cables were finished, a small number of suspenders next to the towers were attached. This was done simultaneously from both towers, and on both sides of each tower, to avoid moving the saddles; when these suspenders were ready the roadway bearers, which are made up of two parallel, low steel, Warren girders, 30 inches deep and 84 feet long, built of 6-inch channels, and 4 and 3-inch angles, were hoisted to about the level they were to occupy, and were fastened by the long bolts, with no attempt at careful adjustment. These beams were so heavy that they were raised in two pieces; one half was suspended from the cables on the right of the bridge, the other

half from those on the left. The bolts were now turned till one half was accurately in prolongation of the other, and the rivets combining them into one were forced in by a hydraulic riveting machine which worked like an ordinary lifting jack, and was found to give better results than hammering. As the roadway advanced more suspenders were hung to the cables, and thus the work progressed with equal speed from the two towers toward the river and toward the anchorages. The utmost care was taken to have the load placed on the cables symmetrically with respect to the towers, the failure to do so would bring severe strains on all parts of the structure. The final adjustment of the elevation of the roadway bearers must be left till they are all in position, because the curvature of the cables changes as the work advances. At the outset the middle rises, and the ends sink; later this is reversed.

Longitudinal trusses. At present all the floor beams are in position, and the construction of the longitudinal trusses has begun and is being rapidly pushed forward. They are six in number, and are to be of the old Whipple type, the tension members extending over two panels. The depth of the outside trusses is 16 feet, of the inner 8 feet. They are not continuous from tower to tower, but consist of two segments, to allow for expansion by heat. Each land span is also composed of two segments. The chords are made of nine-inch channel steel, 90 pounds to the yard, the posts are of 6-inch steel channels.

Stays. A system of over floor stays runs out to the 55th beam on each side of the towers; most of the stays are fastened to heavy irons passing entirely through the towers near the top, the rest pass over the saddles, in special grooves on the sides; these can be seen by inspecting fig. 13. The intention is to have the stays support $\frac{1}{3}$ of the weight of the bridge, but some doubt is felt as to the practicability of the attempt. The chords of the longitudinal trusses which project below the floor are used to support a system of horizontal diagonal bracing. A system of sub-stays fastened to inverted catenaries, which are 135 feet above high water mark for 250 feet in the middle of the river, are spoken of; the object is to brace the bridge against the lifting effect of the wind, and to aid in repressing undulations.

Roadway. The main roadway bearers are supported by the suspenders and are $7\frac{1}{2}$ feet from centre to centre. Half away between them are auxilliary roadway bearers, of 6-inch **I** steel, supported on the longitudinal trusses. A layer of 3-inch yellow pine plank, thoroughly creosoted, is fastened at right angles to the bearers; on this is another layer of the same material—the planks being at right angles to those below.

The longitudinal trusses divide the roadway into five parallel streets; the middle one, which is called the promenade, is solely for foot passengers, and is 5 feet above the others. Next to the promenade comes the tramways for passenger cars, and on the outside the

streets for vehicles. Each of the latter is provided with two tramways, so that two large wagons can be driven side by side.

The roadway passes through the towers, under two pointed arches separated by a central shaft, which interrupts the "promenade." A light iron bridge for foot passengers is fastened to the masonry of this shaft, at such a height as to allow the cars to run under it; by this means pedestrians are enabled to pass round the obstacle. Access is had to this iron foot bridge by flights of steps.

The strength of the bridge, according to the report of the Chief Engineer dated Feb. 9th, 1882, is sufficient to allow the passage of Pullman cars without danger, but it has not yet been decided to allow them to cross, if the proposition be made. The computed strength is such that the factor of safety of the weakest point is, according to the bridge engineers, 2.5 over the elastic limit.

The figures given in the following tables are taken from a paper read before the American Society of Civil Engineers by Mr. Francis Collingwood.

DIMENSIONS OF TOWERS.

DETAILS.	TOWER.				REMARKS.
	Brooklyn		New York.		
	HEIGHT.				
	ft.	in.	ft.	in.	
Bottom of foundation below mean high tide	44	6	78	0	Above high tide, the heights are the same in the two towers.
Base of stone masonry below mean high tide	20	0	46	6	
Depth of water in immediate front of tower	12 to 16 feet.		34	0	
Height of roadway, at tower, above mean high tide	119	3	119	3	
Height of springing line of arches above mean high tide	198	0	198	0	
Height of ridge of roof stone above mean high tide	271	6	271	6	
Height of balustrade on top of tower above mean high tide	276	0	276	0	
Height of balustrade on top of tower above bottom of foundation	320	6	354	0	
Settling	0.101 feet		0.094 feet.		Brooklyn extremes 0.08 and 0.102; New York less differences.
HORIZONTAL SECTIONS AND AREAS.					
	Section, ft.	Area, sq. ft.	Section, ft.	Area, sq. ft.	
At the shoe of the caisson	102 × 168	17136	102 × 172	17544	The towers being hollow, the area of solid masonry is given.
Extreme measurements at base of masonry	69 × 151	8542	77 × 157	9115	
Extreme measurements at high water surface	57 × 141	5172	59 × 141	5968	

DIMENSIONS OF TOWERS. (*Continued.*)

DETAILS.	TOWER. Brooklyn		TOWER. New York.		REMARKS.
Horizontal Sections and Areas.					
Extreme measurements at base of three shafts	Section, ft. 45 × 131	Area, sq. ft. 2297	Section, ft. 48 × 131	Area, sq. ft.	The towers being hollow, the area of solid masonry is given.
Extreme measurements at springing line of arches	42.5 × 128.5	1952	45.5 × 128.5	...	
Extreme measurements at top members of upper cornice	50 × 136	4343	53 × 136		
Volumes.					
Total stone work, excluding balustrades	Cubic yards. 38214		Cubic yards. 46945		About one-third more than in Brooklyn tower.
Total concrete	5669				
" timber and iron	5253				
" cubical contents	49136		62000		Approximate only for New York tower.
Weight of Brooklyn tower and foundation is about 93079 net tons.					

PRESSURES IN THE BROOKLYN TOWER.

DETAILS.	TONS PER SQ. FT.	DETAILS.	TONS PER SQ. FT.
At the bottom of the foundation	5.50	At high tide level	13
At the base of the masonry	9.25	At base of central shaft at level of roadway	26

The last pressure includes the weight from the two central cables, and is the most severe in the structure. It is 361 pounds per square inch. The latest estimate is 32 tons.

COST OF BROOKLYN TOWER.

LABOR AND CONTINGENCIES.	Cost per cu. yard.	MATERIAL.	Cost per cu. yard.
	$		$
Average of whole tower	7.84	Stone (average)	21.00
Between top of caisson and high tide	4.96	Stone (maximum cost)	83.00
Between high tide and roadway	6.36	Stone (minimum cost)	15.00
From roadway to springing lines of arches	9.70	Caisson + labor + filling material	20.71
From springing lines to top	12.60		

ANCHORAGES.

DIMENSIONS.	BROOKLYN. ft.	in.	NEW YORK. ft.	in.	REMARKS.
Timber base, length	119	4	119	0	
Timber base, width	132	0	138	0	Softer soil in New York.

ANCHORAGES. (*Continued.*)

DIMENSIONS.	BROOKLYN.		NEW YORK.		REMARKS.
	ft.	in.	ft.	in.	
Timber base, depth	4	0	4 to 7 ft.		Thicker at river end in New York.
Top of piles below high tide level	0	0	4 to 7 ft.		
Depth of excavation below level of soil.	20 to 25 ft.				
Anchor plates (greatest length)	17	6	17	6	
Anchor plates (greatest width)	16	0	16	0	
Anchor plates (greatest depth)	2	6	2	6	
Cubical contents: Brooklyn anchorage 27113 cubic yards; New York anchorage 28803 cubic yards.					

The following table gives some results obtained by Gen. Newton from data furnished him by the bridge engineers. In the letter he wrote to the President of the Bridge Co. in connection with these results, he states that the factor of safety has been reduced a whole unit, below that required by the commission that approved the plans for the bridge, and that the clear height below the bridge is not 135.00 feet, as it should have been.

DATA.

Distance from intersection of tangents to centre, feet	799.400
Length of cable unloaded at 90 degrees (half span), feet	811.910
Total weight upon each cable (half span), tons	773.245
RESULTS.	
Angle of extreme tangent with horizontal	15° 44′ 00″
Horizontal tension, tons	2,751.10
Extreme tension, tons	2,851.61
Stretch of cable from extreme load (half span), feet	0.853
Total length of cable under extreme load (half span), feet	812.763.
Height of cable at centre, above mean high water of spring, feet	138.061
Bottom of truss below bottom of cable, feet.	4.944
Bottom of truss above mean high water of spring, feet	133.117
Coefficient of safety corresponding to extreme tension	4.14

The following extracts are taken from the letter written by Col. Roebling in March, 1882, in answer to Gen. Newton's communication.

"I agree with you that the margins of safety are very low in the towers and cables of our bridge. The anchorages it has been possible to reinforce, so that a recalculation made last week gives a margin of safety of over three times, which is enough where mere dead weight is concerned. For the other two vital points nothing can be added.

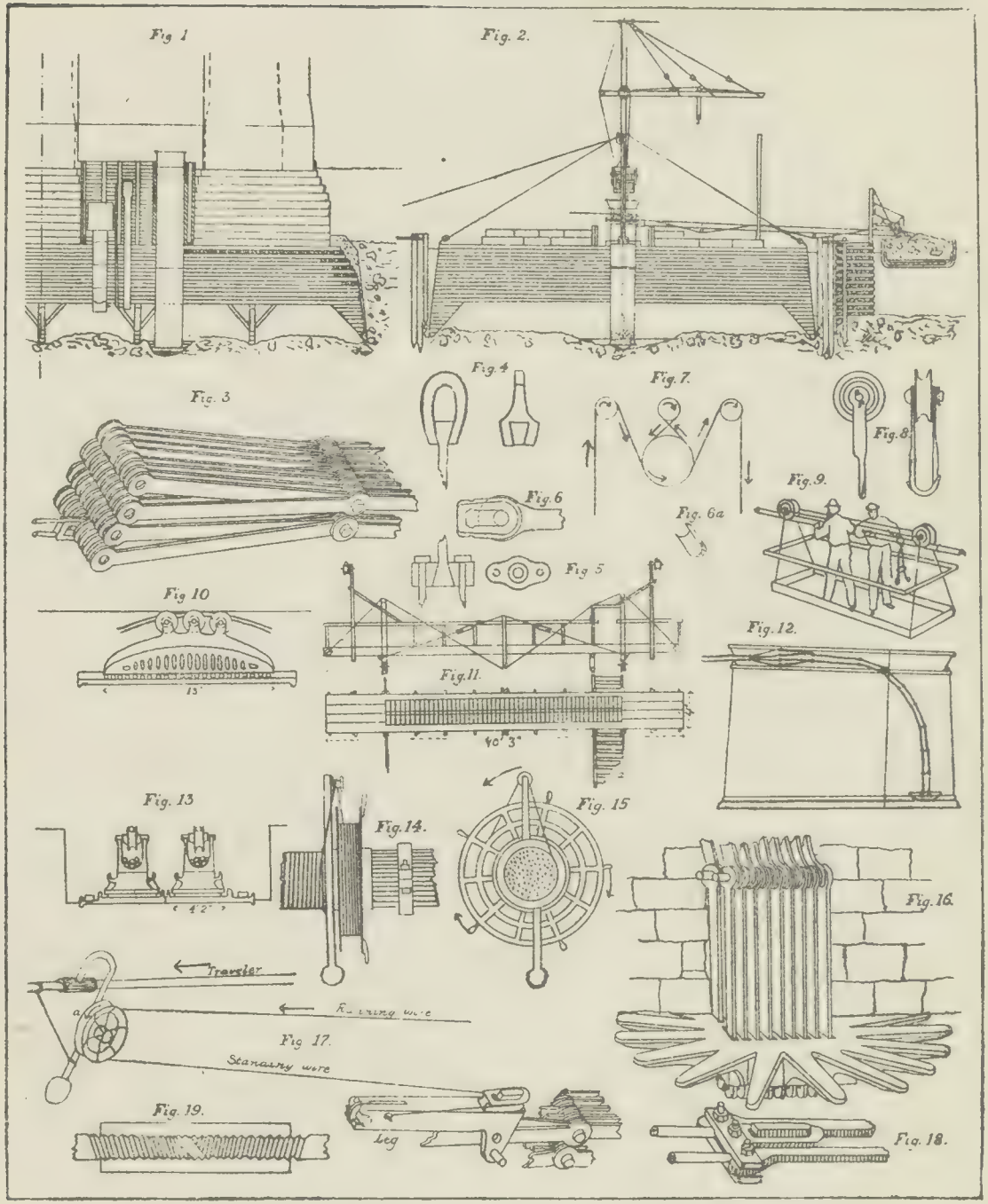
"Among the various causes which have produced this result, I will mention two principal ones:

"*First*—The insufficiency of the original plans and estimates, coupled with the attempt to build for $6,000,000 a work which is going to cost $14,000,000.

"*Second*—The disposition to accommodate to the verge of prudence the pressure of the locomotive interest. To satisfy this interest the structure has been strengthened, the trusses raised five feet, and the weight increased, so that one whole point in the margin of

safety has been wiped out, and the pressure on the tower masonry raised to thirty-two tons per square foot. While I anticipate not even a sign of weakness, relief can be had at any time by lightening the superstructure. The margin is as great as at Niagara, and greater than at Cincinnati. The commission on the Blackwell's Island Bridge recommended a margin of safety of only three. During the recent reconstruction of the Niagara Bridge the permanent load was reduced 200 tons. The cables rose four inches, showing that in twenty-seven years the elasticity of the cables had not been impaired."

BROOKLYN SUSPENSION BRIDGE



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